Where Does Energy R&D Come From? A First Look at Crowding Out from Environmentally-Friendly R&D

David Popp

Maxwell School

Syracuse University

Richard Newell

Nicholas School

Duke University

Disclaimer (added by EPA)

Introduction

- *Question*: Where does new energy R&D come from?
  - Is it new R&D, or does it crowd out other types of R&D?
  - Who performs energy R&D?

- Focus on private sector energy R&D

- Important for climate models and for policy

What We Know About R&D

- **Invention and innovation are the result of:**
  - **Research and Development (R&D)**
  - **Learning by Doing (LBD) & Learning by Using (LBU)**

- **R&D responds to incentives**
  - **Newell, Jaffe, & Stavins (*QJE* 1999), Brunnermeier/Cohen (*JEEM* 2003), Jaffe/Palmer (*REStat* 1997), Popp (*AER* 2002, *JPAM* 2003, *JEEM* 2006), Taylor *et al* . (*Envi Sci Tech* 2003)**
    - **Note that incentives exist in both baseline and with policy**
    - **Baseline incentives depend on the technology**
      - **If there are private benefits (e.g. energy efficiency), some innovation will occur even without policy**
    - **For models calibrated based on current technology applications, business as usual (BAU) ≠ no policy**
      - **Induced innovation models need to focus on marginal innovation**

What We Know About R&D

- **Social returns to research are high**
  - **Public good nature of knowledge leads to spillovers**
  - **Typical result: social returns = 4X private returns**
  - **Evidence for environmental R&D: Popp *REE* 2001, *JPAM* 2003**

- **Models without market failures for research either:**
  - **Overestimate level of innovative activity induced, or**
  - **Implicitly assume policies in place to supplement private R&D**
  - **Results from ENTICE (Popp *JEEM* 2004)**
    - **Welfare gains of ITC increase from 9.4% to 16.7% when market failures are removed**

What We Know About R&D

- **Spillovers make the opportunity costs of R&D important**
  - **Potential sources of new R&D spending:**
    - $Y_t = C_t + I_t + R_{E,t} + R_{O,t}$
  - **Losing \$1 of $R_{O,t}$ has same effect as losing \$4 of I_t or C_t**
  - **Moreover, in many climate models, non-energy technological change is exogenous**
    - $Y = (C, K, E(H(R)), t)$
    - **Essentially, t represents overall technological change**
      - **If there is crowding out, not adjusting this exogenous rate will double-count gains from induced technological change**

What We Know About R&D

- Implications of crowding out
  - For modeling
    - Explains differences across model results
      - E.g. Nordhaus (R&DICE 2002) & Buonanno *et al.* (2003)
      - Results from ENTICE (2004)
        - No crowding out: 45.3%
        - Partial crowding out: 9.4%
        - Full crowding out: 1.9%
    - LBD models may be more optimistic because they ignore the opportunity costs of research

  - For policy
    - Limits potential of ITC under more stringent policies
      - More R&D induced => opportunity costs magnified
    - Limits potential of R&D subsidies

R&D and Climate Change

- **Many climate policy proposals include large increases in energy R&D (de Coninck et al 2008; Newell 2007)**
  - **1997 PCAST & 2004 National Commission on Energy Policy reports both recommended doubling U.S. government energy R&D spending**
  - **Kammen & Nemet (2005) advocate 5-10X increase in energy R&D (an energy "Manhattan Project")**

R&D and Climate Change

- **Two concerns with energy R&D policies**
    1. Need incentives to adopt technology, not just create technology (e.g. Popp 2006)
    2. Opportunity cost of energy R&D will be high if large increases draw R&D resources from other sectors
        - Goolsbee (1998) suggests scientists and engineers (S&E) benefit from increased government R&D support, as this support increases the wages of a fixed supply of S&E

Crowding Out from Energy R&D

- **Unfortunately, there is little empirical work documenting the extent to which increases in energy R&D draw R&D resources away from other sectors.**

- **Where we look:**
  - **Sectoral-level R&D data**
    - **Do increases in economy-wide energy R&D spending draw R&D resources from non-energy sectors to energy sectors?**
  - **Firm-level patent data**
    - **Do increases in energy patents lead to decreases in other types of patents**

Crowding Out Across Sectors

- **Does R&D flow across sectors when energy R&D levels change, so that there is a net draw on R&D away from specific sectors?**

- **Model:**
    - (1) $IRD_{i,t} = f(IRD_{i,t\text{-}1}, Y_{i,t\text{-}1}, FEDRD_{t\text{-}1}, ERD_t)$
        - *IRD*: company-financed R&D performed in industry *i* (NSF)
        - *Y*: value added in industry *i* (BEA)
        - *FEDRD*: federally-funded R&D performed by industry (NSF)
        - *ERD*: total company-financed energy R&D (NSF)
            - Instruments: lagged independent variables, price of energy, defense spending, & lagged federal energy R&D spending

Crowding Out Across Sectors

- **Data limitation:**
  - **Energy R&D** variable is *economy-wide*, rather than *industry-specific*
    - **Industry-level data only available for select industries and for certain years**

- **Identification strategy**
  - **Separate industries by % energy R&D**
    - **Low energy R&D industries: 0** coefficient on ERD => no **crowding out**
    - **High energy R&D industries:** 0 **coefficient on ERD => crowding out**

Industry Data, 1983-1997

Industry	mean R&D	mean VA	mean R&D/VA	mean % energy R&D
Petroleum refining and extraction	2,429	135,536	1.9%	51.4%
Electrical equipment	13,197	125,682	10.4%	8.7%
Nonmanufacturing	15,789	487,836	2.9%	8.4%
Primary metals	817	49,976	1.7%	7.1%
Transportation equipment	16,727	132,207	12.6%	5.9%
Fabricated metal products	975	80,015	1.2%	3.5%
Chemicals and allied products	13,945	117,558	11.8%	3.2%
Lumber, wood products, and furniture	250	53,943	0.5%	2.4%
Rubber products	1,078	39,516	2.7%	2.1%
Machinery	12,971	128,508	10.1%	2.0%
Stone, clay, and glass products	734	30,349	2.5%	1.9%
Other manufacturing industries	856	103,745	0.8%	0.7%
Professional and scientific instrument	6,974	44,042	16.1%	0.6%
Paper and allied products	1,083	48,454	2.2%	0.4%
Food, kindred, and tobacco products	1,460	118,867	1.2%	0.3%
Textiles and apparel	300	53,845	0.6%	0.2%
all industries w/energy R&D > 5%	9,792	186,247	5.9%	
all industries w/energy R&D < 5%	3,693	74,440	4.5%	

Industry Data, 1973-1997

Industry	mean R&D	mean VA	mean R&D/VA	mean % energy R&D
Petroleum refining and extraction	2,163	121,537	1.9%	56.3%
Nonmanufacturing	10,707	443,782	2.0%	16.1%
Electrical equipment	11,097	108,781	10.0%	12.5%
Primary metals	856	57,170	1.5%	7.7%
Chemicals and allied products	11,166	102,409	10.5%	3.8%
Fabricated metal products	889	76,251	1.2%	3.5%
Machinery	10,807	121,355	8.8%	1.7%
all industries w/energy R&D > 5%	6,206	182,818	3.9%	
all industries w/energy R&D < 5%	7,621	100,005	6.8%	

Energy R&D Trends, 1973-1997
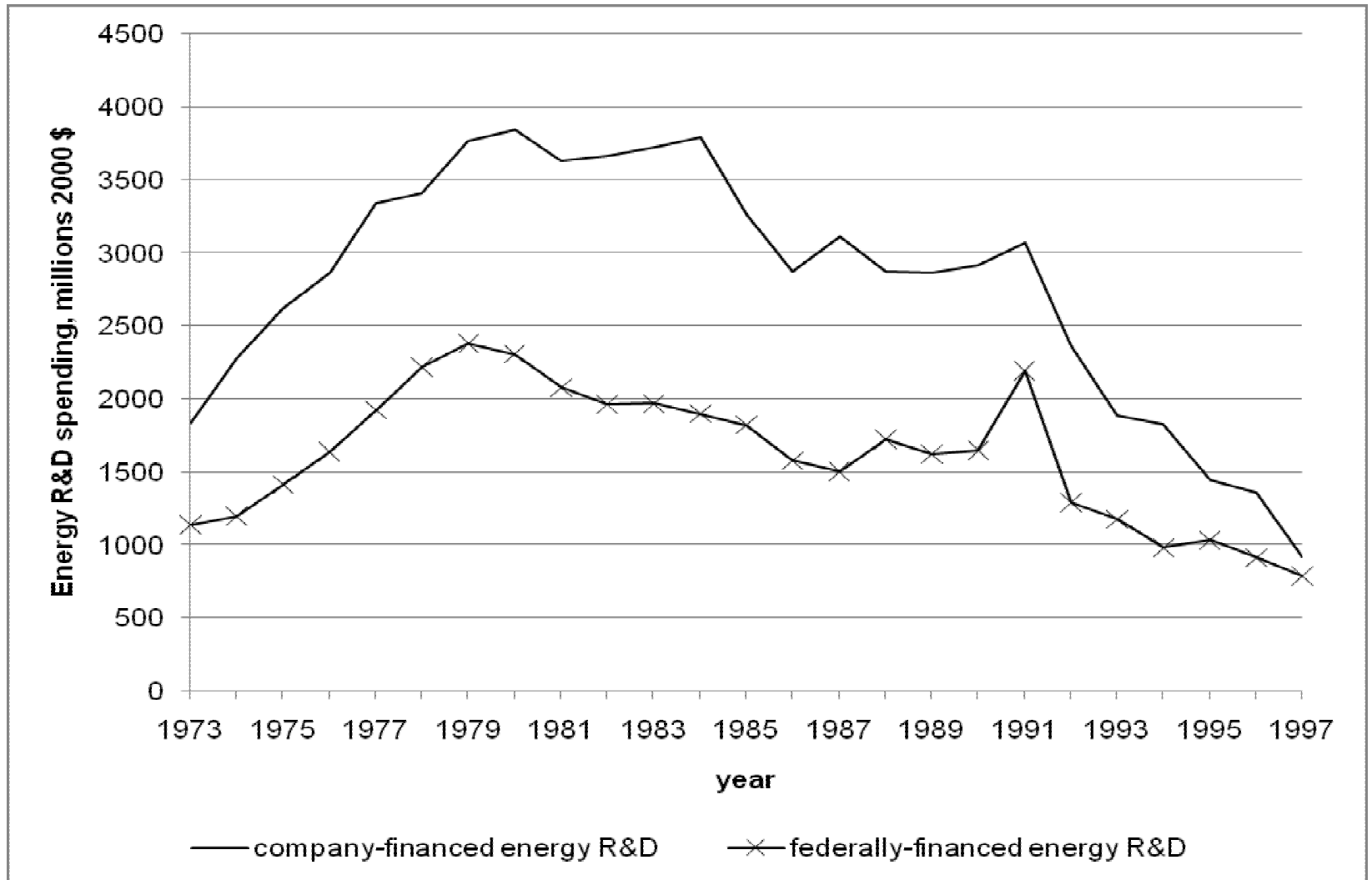
Results: 1983-1997

- **Low energy R&D sectors:**
  - No evidence of crowding out
  - Economy-wide energy R&D increases do not draw R&D from non-energy R&D performing sectors

Results, 1983-1997

Variable	low energy R&D		high energy R&D		no refineries	
	< 1%	< 5%	> 1%	> 5%	> 1%	> 5%
R&D(i,t-1)	0.9069	0.8790	0.7924	0.7749	0.7458	0.6640
	(0.0628)	(0.0778)	(0.0702)	(0.0795)	(0.0897)	(0.0971)
energy R&D (t)	0.0150	0.0241	0.0138	-0.2665	0.2858	0.1217
	(0.0266)	(0.0809)	(0.1247)	(0.1841)	(0.1325)	(0.1835)
Value Added(i,t-1)	0.0046	0.0076	0.0264	0.0272	0.0390	0.0485
	(0.0027)	(0.0077)	(0.0089)	(0.0092)	(0.0125)	(0.0125)
Federal R&D(t-1)	-0.0059	-0.0118	-0.0274	-0.0521	-0.0467	-0.1129
	(0.0028)	(0.0071)	(0.0156)	(0.0284)	(0.0152)	(0.0296)
N	75	165	165	75	150	60
r2	0.8963	0.7320	0.9188	0.9480	0.9241	0.9539

standard errors in parentheses

Results: 1983-1997

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- **High energy R&D sectors:**
  - Results suggest crowding out
  - Increases in energy R&D are not *new* R&D
  - Harder to interpret:
    - What about intermediate industries?
    - What level represents no crowding out?

Results, 1983-1997

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- **Other variables consistent with expectations**
  - Gradual adjustment
  - About 1-4% of industry output devoted to R&D
  - Some evidence of crowding out from federal R&D

Results, 1983-1997

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| | | | | | no refineries | |
	< 1%	< 5%	> 1%	> 5%	> 1%	> 5%
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r2	0.8963	0.7320	0.9188	0.9480	0.9241	0.9539

standard errors in parentheses

Results: 1973-1997

- **Results are similar**
  - **No crowding out in low energy R&D industries**
  - **However, negative sign for high energy R&D industries is a concern**
    - **Doesn't go away when eliminate petroleum refining**

Results, 1973-1997

| Variable | low energy R&D | | high energy R&D | | | |
| | | | | | no refineries | |
	< 5%	< 10%	> 5%	> 10%	> 5%	> 10%
R&D(i,t-1)	0.8628	0.8922	0.8891	0.8419	0.9094	0.7217
	(0.0893)	(0.0716)	(0.0629)	(0.0712)	(0.0830)	(0.1070)
energy R&D (t)	0.2198	0.1482	-0.3363	-0.5292	-0.3037	-0.5702
	(0.1928)	(0.1424)	(0.1275)	(0.1863)	(0.1498)	(0.2830)
Value Added(i,t-1)	0.0255	0.0159	0.0172	0.0219	0.0158	0.0384
	(0.0151)	(0.0098)	(0.0063)	(0.0076)	(0.0096)	(0.0141)
Federal R&D(t-1)	0.0244	0.0248	-0.0106	-0.0312	-0.0073	-0.0654
	(0.0176)	(0.0146)	(0.0146)	(0.0221)	(0.0203)	(0.0344)
N	72	96	96	72	72	48
r2	0.9019	0.8986	0.9698	0.9693	0.9718	0.9729

standard errors in parentheses

Estimate Firm-level R&D

- **Problem for high-energy industries: not all energy R&D spending does not go to a single industry**

- **Solution: estimate economy-wide energy R&D going to each industry**
  - **Multiply economy-wide energy R&D data by average share of energy R&D going to that industry from years in which industry-specific data are available**
  - **Null hypothesis of no crowding out => coefficient equals 1**
  - **We can reject the null hypothesis, but the results are very imprecise**

Results with Estimated Energy R&D

| Variable | high energy R&D 1973-1997 | | | | high energy R&D 1983-1997 | | | |
| | | | no refineries | | | | no refineries | |
	> 5%	> 10%	> 5%	> 10%	> 1%	> 5%	> 1%	> 5%
R&D(i,t-1)	0.8689	0.8408	0.9079	0.7475	0.8159	0.7777	0.7935	0.6811
	(0.0664)	(0.0738)	(0.0831)	(0.1059)	(0.0701)	(0.0818)	(0.0809)	(0.1004)
energy R&D (i,t)	-0.9370	-1.0558	-2.5069	-3.2278	-0.9229	-1.0799	2.5437	1.1388
	(0.5051)	(0.5711)	(1.3927)	(2.1695)	(0.6200)	(0.6953)	(2.9061)	(2.6775)
Value Added(i,t-1)	0.0214	0.0256	0.0151	0.0357	0.0236	0.0298	0.0313	0.0449
	(0.0069)	(0.0084)	(0.0094)	(0.0138)	(0.0080)	(0.0096)	(0.0113)	(0.0135)
Fed R&D(t-1)	-0.0055	-0.0307	-0.0026	-0.0578	-0.0256	-0.0581	-0.0423	-0.1047
	(0.0151)	(0.0240)	(0.0200)	(0.0346)	(0.0145)	(0.0258)	(0.0149)	(0.0301)
N	96	72	72	48	165	75	150	60
r2	0.9693	0.9694	0.9716	0.9730	0.9201	0.9488	0.9226	0.9538

Crowding Out Within Sectors

- **While our results for high energy R&D sectors suggest possible crowding out, data limitations lead to weak results.**
  - Thus, we turn to a more detailed, firm-level analysis.

- **Do increases in energy R&D *at the firm level* crowd out other types of R&D?**

- **Because energy R&D data are not available at the firm level, we use patents to identify energy R&D**

- **Two focuses:**
  - Alternative energy
  - Energy R&D in the automotive sector

Crowding Out Within Sectors

- **Model:**

  (2) $OPAT_{i,t} = f(OPAT_{i,t-1}, EPAT_{i,t}, X_{i,t}, a_i, b_t)$

  - $OPAT_{i,t}$: other patents assigned to firm i from app year t
  - $EPAT_{i,t}$: energy patents assigned to firm i from app year t
  - $X_{i,t}$: other firm characteristics (Capital, Sales)
  - a_i: firm fixed effects
  - b_t: year fixed effects

- **Estimation:**

  - GMM estimation, correcting for both autocorrelation and heteroskedasticity
  - Lagged independent variables used as instruments

Data

- **Two sources for patent data (1971-2002)**
  - **Identify relevant patents using Delphion data base**
    - **Alternative energy patents include:**
      - **Coal Liquefaction**
      - **Coal Gasification**
      - **Solar Energy**
      - **Solar Energy – Batteries**
      - **Fuel Cells**
      - **Wind**
      - **Using waste as fuel**
      - **Geothermal energy**
    - **Automotive energy patents include:**
      - **Hybrids**
      - **Fuel Cells**
      - **Improved energy efficiency**
  - **Used the NBER patent database (Hall, Jaffe, Trajtenberg 2001) to identify all patents assigned to these firms**

Data

- **Next step: identify relevant firms**
  - **Focused on firms where energy patents are 1.5 - 67% of all patents**
    - **Eliminates firms where most patents are energy related (crowding out not an issue) or few patents are energy related**
  - **Searched for Compustat data for the remaining firms**
    - **14 firms for automotive technologies**
    - **32 firms for alternative energy**

- **Sort patents by year of application**
  - **To avoid truncation problems, use data from 1970-1999**

Who Patents?

- **The distribution of patenting firms is highly skewed**
  - **Alternative energy: 18,107 total patents**
    - **Firms in our regression have 2,011 patents (11%).**
    - **3,059 unique patent assignees**
      - **Of these, 1,935 have just one alternative energy patent**
    - **Only 17% of alternative energy patents are assigned to the top 20 assignees**
  - **Automotive energy technologies: 9,895 total patents**
    - **Firms in our regression have 1,269 patents (13%)**
    - **1,438 unique patent assignees**
      - **Of these, 813 have just one automotive energy patent**
    - **32% of patents are assigned to the top 20 assignees (not counting individually assigned patents)**

Top 20 Assignees – Total Energy Patents

Alternative Energy

Assignee	Energy patents	All patents	% energy
Individually Owned Patents	4457	521560	0.85%
Exxon	340	7839	4.34%
Canon	318	24454	1.30%
US Department of Energy	303	6028	5.03%
Siemens Aktiengesellschaft	216	16024	1.35%
United Technologies	201	5655	3.55%
Westinghouse Electric	180	10891	1.65%
International Fuel Cells Corp	179	244	73.36%
General Electric	147	27557	0.53%
Mobil	137	6798	2.02%
Atlantic Richfield Copmany	131	2323	5.64%
Sanyo Electric	122	3047	4.00%
Hitachi	116	24920	0.47%
Texaco	115	4523	2.54%
Chevron	111	3332	3.33%
Foster Wheeler	106	565	18.76%
NASA	106	4177	2.54%
Mitsubishi	101	20951	0.48%
Energy Conversion Devices	94	429	21.91%
Fuji Electric	91	1478	6.16%
TOTAL (top 20 except ind.)	3114		
ALL ASSIGNEES	**18107**	**2933721**	**0.62%**

Automotive

Assignee	Energy patents	All patents	% energy
Individually Owned Patents	1624	521560	0.31%
Ford Motor Company	345	7785	4.43%
Toyota	335	7083	4.73%
Honda	300	7243	4.14%
Nissan	209	6947	3.01%
International Fuel Cells	199	244	81.56%
United Technologies Corp	181	5655	3.20%
General Motors	180	11408	1.58%
Mitsubishi	159	20951	0.76%
Hitachi	153	24920	0.61%
General Electric	150	27557	0.54%
Westinghouse Electric	138	10891	1.27%
Siemens	133	16024	0.83%
Robert Bosch	108	9002	1.20%
Mobil	98	6798	1.44%
US Department of Energy	98	6028	1.63%
Daimler-Chrysler	88	2196	4.01%
Cummins Engine	85	682	12.46%
Ballard Power Systems	84	90	93.33%
NGK Insulators Ltd.	82	2597	3.16%
TOTAL (top 20 except ind.)	3125		
ALL ASSIGNEES	**9895**	**2933721**	**0.34%**

Top 20 Assignees – % Energy Patents

Alternative Energy

Assignee	Energy patents	All patents	% energy
JX Crystals, Inc.	23	23	100.00%
Solarco Corporation	12	12	100.00%
Sunworks, Inc.	12	12	100.00%
Magma Power Company	10	10	100.00%
H-Power Corp.	15	16	93.75%
Electrochemische Energieconversie N.V.	12	13	92.31%
Solarex Corporation	55	60	91.67%
M-C Power Corporation	11	12	91.67%
Chronic Corporation	24	27	88.89%
Plug Power L.L.C.	53	60	88.33%
Sovoncis Solar Systems	19	23	82.61%
Spectrolab, Inc.	13	16	81.25%
ZTek Corporation	13	16	81.25%
Ballard Power Sytems, Inc.	73	90	81.11%
Astropower, Inc.	12	15	80.00%
AER Energy Resources, Inc.	38	49	77.55%
United Solar Systems Corp	33	44	75.00%
International Fuel Cells	179	244	73.36%
Evergreen Solar, Inc.	11	15	73.33%
Photon Power, Inc.	16	23	69.57%
TOTAL (top 20)	634		
ALL ASSIGNEES	18107	2933721	0.62%

Automotive

Assignee	Energy patents	All patents	% energy
H-Power Corp.	16	16	100.00%
ZTek Corporation	16	16	100.00%
Ballard Power Systems, Inc.	84	90	93.33%
Plug Power L.L.C.	54	60	90.00%
M-C Power Corporation	10	12	83.33%
International Fuel Cells Corp	199	244	81.56%
Phillips & Temro Industries	11	16	68.75%
Energy Research Corp	58	91	63.74%
National Power PLC	11	19	57.89%
Xcellsis GmbH	17	31	54.84%
Electric Fuel Limited	16	36	44.44%
AER Energy Resources, Inc	18	49	36.73%
Kabushikikaiha Equos	23	64	35.94%
Lynntech, Inc.	21	61	34.43%
Energy Development Assoc	21	68	30.88%
Tanaka Kikinzoku Kogyo	19	77	24.68%
Reveo, Inc.	19	77	24.68%
SMH Management Services	10	53	18.87%
Detroit Diesel Corporation	19	113	16.81%
Ceramatec, Inc.	10	61	16.39%
TOTAL (top 20)	652		
ALL ASSIGNEES	9895	2933721	0.34%

Total Alternative Energy Patents from All Energy Firms, by Application Year
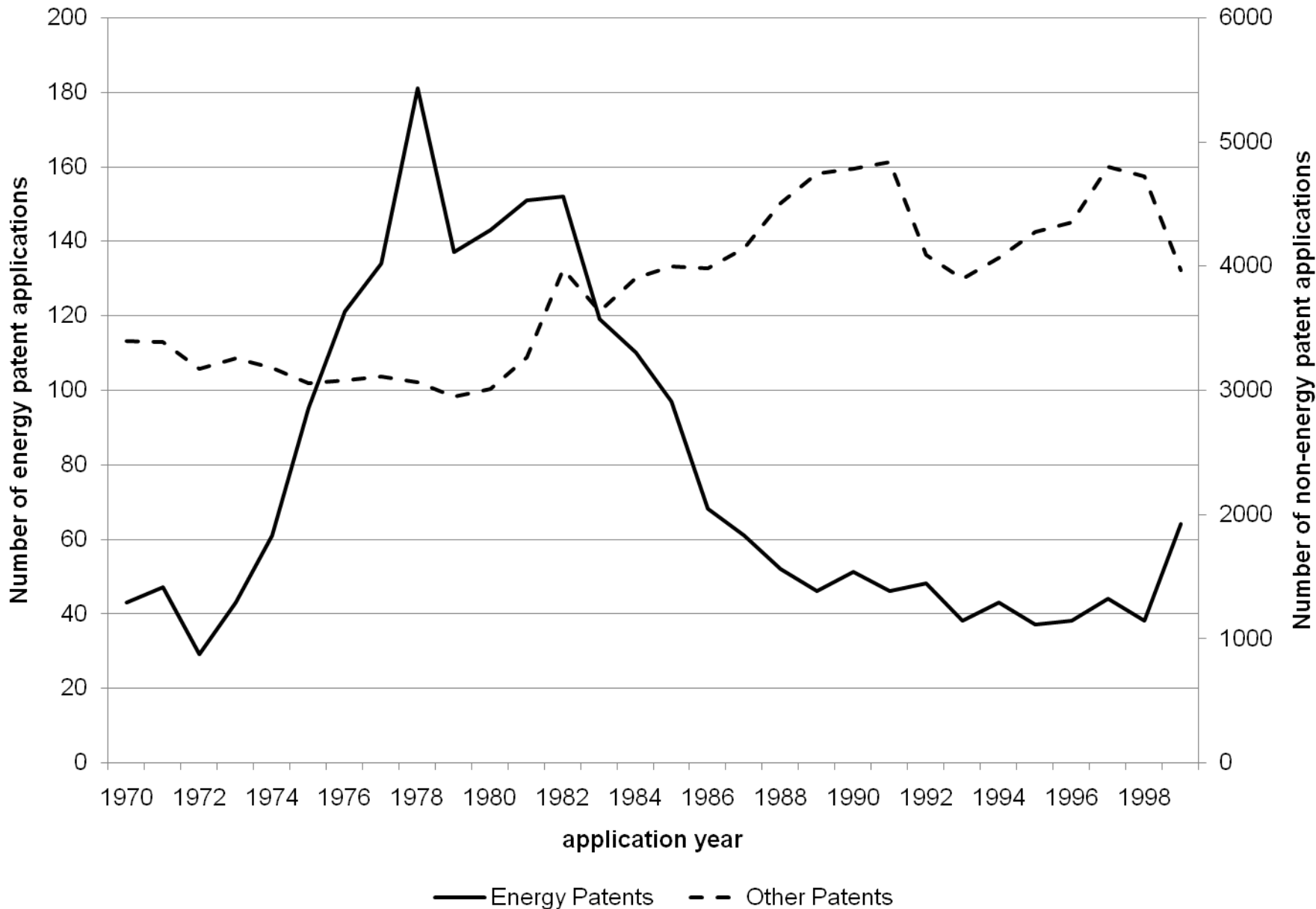
Total Automotive Energy Patents from All Energy Firms, by Application Year

Number of energy patent applications (left axis); Number of non-energy patent applications (right axis); application year (x-axis)

Legend: —— Energy Patents — – Other Patents

Results: Alternative Energy

- **Results suggestive of crowding out, but only significant at 10% level**

Estimation Results: Alternative energy

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Other Patents (t-1)	0.547	0.840	0.682	0.630	0.857	0.731
	(3.161)	(3.338)	(4.078)	(3.966)	(3.360)	(4.808)
Energy Patents(t)	-1.177	-1.167	-1.547	-1.065	-0.446	-1.169
	(-1.877)	(-1.147)	(-1.875)	(-1.687)	(-0.533)	(-1.541)
Sales (t-1)	0.947		0.795	0.802		0.699
	(2.175)		(2.204)	(2.101)		(2.075)
Capital(t)		-0.476	-0.551		-0.174	-0.375
		(-0.627)	(-1.028)		(-0.216)	(-0.728)
trend				-0.983	-0.545	-0.813
				(-3.854)	(-1.607)	(-3.043)
Year Dummies	YES	YES	YES	NO	NO	NO
N	620	620	620	620	620	620
r2	0.598	0.621	0.618	0.602	0.609	0.610
p-value for Hansen's J	0.587	0.355	0.853	0.450	0.105	0.583
Kleibergen-Paap rk Wald F statistic	3.731	1.844	2.079	3.528	1.478	2.259
p-value from underidentification test	0.002	0.130	0.033	0.001	0.229	0.013

Results: Alternative Energy

- **Results suggestive of crowding out, but only significant at 10% level**

- **Lagged coefficient supports gradual adjustment**

Estimation Results: Alternative energy

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Other Patents (t-1)	0.547	0.840	0.682	0.630	0.857	0.731
	(3.161)	(3.338)	(4.078)	(3.966)	(3.360)	(4.808)
Energy Patents(t)	-1.177	-1.167	-1.547	-1.065	-0.446	-1.169
	(-1.877)	(-1.147)	(-1.875)	(-1.687)	(-0.533)	(-1.541)
Sales (t-1)	0.947		0.795	0.802		0.699
	(2.175)		(2.204)	(2.101)		(2.075)
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		(-0.627)	(-1.028)		(-0.216)	(-0.728)
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Results: Alternative Energy

- **Results suggestive of crowding out, but only significant at 10% level**
  - **In these models, all variables are insignificant**

- **Lagged coefficient supports gradual adjustment**

- **Sales have a positive effect**
  - **Suggestive of firms facing financial constraints**

- **Capital insignificant**

Estimation Results: Alternative energy

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Other Patents (t-1)	0.547	0.840	0.682	0.630	0.857	0.731
	(3.161)	(3.338)	(4.078)	(3.966)	(3.360)	(4.808)
Energy Patents(t)	-1.177	-1.167	-1.547	-1.065	-0.446	-1.169
	(-1.877)	(-1.147)	(-1.875)	(-1.687)	(-0.533)	(-1.541)
Sales (t-1)	0.947		0.795	0.802		0.699
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		(-0.627)	(-1.028)		(-0.216)	(-0.728)
trend				-0.983	-0.545	-0.813
				(-3.854)	(-1.607)	(-3.043)
Year Dummies	YES	YES	YES	NO	NO	NO
N	620	620	620	620	620	620
r2	0.598	0.621	0.618	0.602	0.609	0.610
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Results: Alternative Energy

- **Results suggestive of crowding out, but only significant at 10% level**
  - **In these models, all variables are insignificant**

- **Lagged coefficient supports gradual adjustment**

- **Sales have a positive effect**
  - **Suggestive of firms facing financial constraints**

- **Capital insignificant**

- **However, we have a weak instruments problem**

Estimation Results: Alternative energy

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Other Patents (t-1)	0.547	0.840	0.682	0.630	0.857	0.731
	(3.161)	(3.338)	(4.078)	(3.966)	(3.360)	(4.808)
Energy Patents(t)	-1.177	-1.167	-1.547	-1.065	-0.446	-1.169
	(-1.877)	(-1.147)	(-1.875)	(-1.687)	(-0.533)	(-1.541)
Sales (t-1)	0.947		0.795	0.802		0.699
	(2.175)		(2.204)	(2.101)		(2.075)
Capital(t)		-0.476	-0.551		-0.174	-0.375
		(-0.627)	(-1.028)		(-0.216)	(-0.728)
trend				-0.983	-0.545	-0.813
				(-3.854)	(-1.607)	(-3.043)
Year Dummies	YES	YES	YES	NO	NO	NO
N	620	620	620	620	620	620
r2	0.598	0.621	0.618	0.602	0.609	0.610
p-value for Hansen's J	0.587	0.355	0.853	0.450	0.105	0.583
Kleibergen-Paap rk Wald F statistic	3.731	1.844	2.079	3.528	1.478	2.259
p-value from underidentification test	0.002	0.130	0.033	0.001	0.229	0.013

Results: Alternative Energy

- **Weak instruments problem comes from the lagged dependent variable**
  - *F*-stat for 1st stage regression: 3.79
  - *F*-stat for 1st stage regression of energy patents: 25.04

- **To address this, we re-run the model without the lagged dependent variable**
  - Little change in the coefficients
  - In one case, we can reject the null of no crowding out at a 5% significance level

Estimation Results: Alternative energy

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Other Patents (t-1)	0.547		0.682		0.630		0.731	
	(3.161)		(4.078)		(3.966)		(4.808)	
Energy Patents(t)	-1.177	-1.468	-1.547	-1.073	-1.065	-1.774	-1.169	-1.324
	(-1.877)	(-1.715)	(-1.875)	(-1.025)	(-1.687)	(-2.176)	(-1.541)	(-1.358)
Sales (t-1)	0.947	2.055	0.795	1.932	0.802	1.956	0.699	1.786
	(2.175)	(6.378)	(2.204)	(5.062)	(2.101)	(6.309)	(2.075)	(4.673)
Capital(t)			-0.551	0.602			-0.375	0.772
			(-1.028)	(0.887)			(-0.728)	(1.106)
trend					-0.983	-1.805	-0.813	-1.882
					(-3.854)	(-7.158)	(-3.043)	(-7.459)
Year Dummies	YES	YES	YES	YES	NO	NO	NO	NO
N	620	620	620	620	620	620	620	620
r2	0.598	0.176	0.618	0.192	0.602	0.128	0.610	0.151
p-value for Hansen's J	0.587	0.139	0.853	0.284	0.450	0.145	0.583	0.235
Kleibergen-Paap rk Wald F stat	3.731	25.043	2.079	12.808	3.528	20.220	2.259	13.320
p-value from underidentification	0.002	2.2E-08	0.033	4.6E-09	0.001	4.0E-10	0.013	3.4E-11

Results: Automotive Sector

- **Results are weaker**
  - **Signs as expected, but only the lagged dependent variable is significant**
    - **Fewer observations may be an issue**

- **These firms are larger, so that no crowding out is a feasible result**

Estimation Results: Automotive

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Other Patents (t-1)	0.727	1.062	0.808	0.703	0.901	0.854
	(3.342)	(1.996)	(1.616)	(3.602)	(2.180)	(2.438)
Energy Patents(t)	-1.968	-5.598	-2.086	-1.299	-2.867	-1.868
	(-0.606)	(-0.848)	(-0.365)	(-0.618)	(-0.693)	(-0.595)
Sales (t-1)	1.246		0.687	1.046		0.280
	(1.768)		(0.633)	(1.656)		(0.270)
Capital(t)		3.015	1.120		2.339	1.621
		(1.628)	(0.362)		(1.601)	(0.665)
trend				0.179	-0.064	-0.159
				(0.336)	(-0.059)	(-0.194)
Year Dummies	YES	YES	YES	NO	NO	NO
N	281	281	281	281	281	281
r2	0.641	0.517	0.650	0.636	0.611	0.642
p-value for Hansen's J	0.103	0.464	0.241	0.037	0.580	0.070
Kleibergen-Paap rk Wald F statistic	2.968	2.087	1.155	2.126	2.082	1.248
p-value from underidentification test	0.041	0.318	0.384	0.110	0.077	0.247

Results: Automotive Sector

- **Results are weaker**
  - **Signs as expected, but only the lagged dependent variable is significant**
    - **Fewer observations may be an issue**

- **These firms are larger, so that no crowding out is a feasible result**

- **As before, dropping the lagged dependent variable solves the weak instruments problem**
  - **However, the results are less satisfactory**

Estimation Results: Automotive

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Other Patents (t-1)	0.727		0.808		0.703		0.854	
	(3.342)		(1.616)		(3.602)		(2.438)	
Energy Patents(t)	-1.968	2.923	-2.086	4.646	-1.299	2.225	-1.868	3.828
	(-0.606)	(0.891)	(-0.365)	(1.545)	(-0.618)	(0.969)	(-0.595)	(1.861)
Sales (t-1)	1.246	1.591	0.687	2.713	1.046	1.547	0.280	2.424
	(1.768)	(1.575)	(0.633)	(2.462)	(1.656)	(1.894)	(0.270)	(2.623)
Capital(t)			1.120	-3.463			1.621	-2.963
			(0.362)	(-1.921)			(0.665)	(-1.562)
trend					0.179	1.006	-0.159	1.119
					(0.336)	(1.500)	(-0.194)	(1.567)
Year Dummies	YES	YES	YES	YES	NO	NO	NO	NO
N	281	281	281	281	281	281	281	281
r2	0.641	0.402	0.650	0.458	0.636	0.350	0.642	0.399
p-value for Hansen's J	0.103	0.076	0.241	0.472	0.037	0.040	0.070	0.090
Kleibergen-Paap rk Wald F stat	2.968	15.837	1.155	10.090	2.126	16.072	1.248	11.817
p-value from underidentification	0.041	1.3E-05	0.384	9.6E-06	0.110	0.001	0.247	0.001

Conclusions

- **We find no evidence that energy R&D draws resources away from non-energy R&D performing sectors**
  - **Mitigates some concerns over crowding out**

- **Results in energy R&D sectors are mixed**
  - **Industry level regressions suggest energy R&D does crowd out other R&D in these sectors**
  - **Firm-level regressions find weak evidence of crowding out within firms researching alternative energy**

Thank You

Descriptive Statistics by Firm

Company	Freq.	alt. energy patents	auto energy patents	all patents	pct alt energy (average)	pct alt energy (pct of total)	pct auto energy (average)	pct auto energy (pct of total)	Capital (billions 2000 $)	Sales (billions 2000 $)
Volvo	17	0.06	0.41	20.53	0.45%	0.29%	1.90%	2.01%	3.58	18.70
Allis-Chalmers	15	0.53	0.27	59.07	0.88%	0.90%	0.32%	0.45%	0.54	2.91
Ametek, Inc.	30	0.53		6.27	9.39%	8.51%			0.15	0.70
Amoco Corporation	28	2.21	0.50	90.36	2.47%	2.45%	0.58%	0.55%	20.67	27.98
Atlantic Richfield	30	4.20	0.27	72.00	5.23%	5.83%	0.38%	0.37%	16.71	20.77
Babcock & Wilcox	7	0.57	0.00	32.29	1.44%	1.77%	0.00%	0.00%	0.76	3.29
Chevron	30	3.60	0.67	102.00	2.77%	3.53%	0.68%	0.65%	20.48	37.47
Chrysler	28		2.04	65.39			3.37%	3.11%	8.75	33.39
Cities Service Company	17	1.06		21.12	10.65%	5.01%			5.02	6.99
Combustion Engineering, Inc.	19	3.05	0.05	54.63	5.26%	5.59%	0.15%	0.10%	0.79	4.04
Conoco	30	1.47		47.93	2.15%	3.06%			9.23	14.45
Cummins Engine Company	30		2.67	20.77			8.63%	12.84%	0.93	3.47
Daimler-Benz	10	0.40	2.20	98.50	0.38%	0.41%	1.79%	2.23%	17.69	67.31
Daimler-Chrysler	2	3.00	19.50	560.00	0.69%	0.54%	3.71%	3.48%	61.56	162.32
Detroit Diesel	8		1.50	8.25			14.32%	18.18%	0.25	2.07
Dorr-Oliver	9	0.89		8.33	10.34%	10.67%			0.02	0.30
Energy Conversion Devices	30	3.07	0.27	13.10	14.33%	23.41%	2.65%	2.04%	0.01	0.02
Engelhard Corporation	19	1.32	2.11	24.16	5.89%	5.45%	9.45%	8.71%	0.60	3.13
Exxon	30	11.07	2.20	240.70	4.38%	4.60%	0.88%	0.91%	57.55	110.49
Ford Motor Company	30	0.83	8.00	233.73	0.51%	0.36%	2.96%	3.42%	20.84	92.64
Foster Wheeler	30	3.43		17.57	19.69%	19.54%			0.38	2.41
General Motors	30	1.73	4.70	353.67	0.69%	0.49%	1.69%	1.33%	38.43	124.77
Grumman Aerospace Corp.	24	0.83		29.25	4.77%	2.85%			0.40	3.39
Gulf	12	5.08	0.00	79.50	6.13%	6.39%	0.00%	0.00%	0.05	0.04
Honda	30	0.93	8.17	215.63	0.23%	0.43%	2.99%	3.79%	5.13	23.80

Descriptive Statistics by Firm

Company	Freq.	alt. energy patents	auto energy patents	all patents	pct alt energy (average)	pct alt energy (pct of total)	pct auto energy (average)	pct auto energy (pct of total)	Capital (billions 2000 $)	Sales (billions 2000 $)
Kerr-McGee	30	0.97	0.03	3.30	26.24%	29.29%	2.00%	1.01%	2.59	3.50
Lubrizol	30		1.23	27.43			4.18%	4.50%	0.41	1.30
Mobil	29	4.59	3.31	224.86	1.89%	2.04%	1.40%	1.47%	24.40	60.91
Molten Metal Technology, Inc.	5	1.60		6.60	22.67%	24.24%			0.04	0.03
Nissan	11	0.00	6.55	213.73	0.00%	0.00%	2.99%	3.06%	26.92	56.98
Northrop Grumman Corporation	30	0.20	0.47	41.80	0.29%	0.48%	0.34%	1.12%	1.03	5.12
Occidental	30	2.67	0.37	29.73	6.94%	8.97%	1.18%	1.23%	10.20	14.74
Optical Coating Laboratory, Inc.	30	0.37		4.50	9.13%	8.15%			0.05	0.11
Owens-Illinois	30	1.23		65.53	1.34%	1.88%			2.29	4.89
Praxair Technology, Inc.	9	1.33	0.56	55.56	2.53%	2.40%	1.07%	1.00%	3.64	3.83
Sanyo Electric	10	6.50	2.40	188.40	4.14%	3.45%	1.34%	1.27%	5.19	16.12
Shell	30	2.73	0.33	187.43	1.34%	1.46%	0.20%	0.18%	31.47	57.47
Spire Corp.	18	0.44	2.72		13.97%	16.33%			0.01	0.02
Standard Oil	17	2.12	0.29	77.53	2.75%	2.73%	0.41%	0.38%	10.45	10.46
Texaco	30	3.57	0.50	140.97	2.76%	2.53%	0.49%	0.35%	20.09	47.28
Tosco Corporation	30	0.30		1.03	25.97%	29.03%			0.86	3.87
Toshiba	25	2.80	1.76	779.12	0.42%	0.36%	0.29%	0.23%	7.46	30.98
Toyota	18	2.44	13.67	266.11	0.70%	0.92%	4.65%	5.14%	20.44	75.09
United Technologies	30	6.13	5.47	178.30	3.58%	3.44%	3.16%	3.07%	3.31	18.20
UOP	8	5.38	0.25	181.88	2.99%	2.96%	0.16%	0.14%	0.33	1.67
Varian Associates	28	0.79		35.36	2.28%	2.22%			0.21	1.12
Westinghouse Electric	22	6.82	4.82	423.96	1.70%	1.61%	1.21%	1.14%	3.28	13.83