R&D, Energy, and Growth - A Theoretical Framework (PRELIMINARY)

Ted Temzelides

Rice University

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- Role for Policy.

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- Investments in energy R&D in US fell by 50% between 1991 and 2003.

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- Is this optimism justified?

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- Discussion and Extensions

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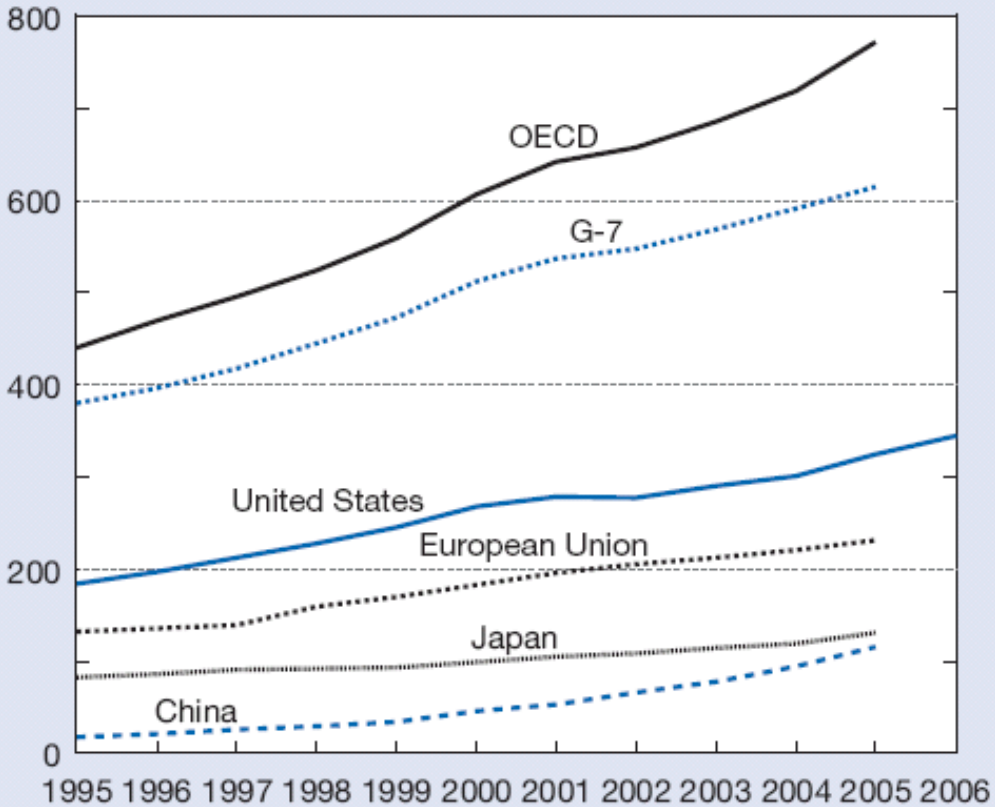
- Persistent differences in R&D intensity across firms.
- Proposed model consistent with these facts.

Sources: Bental et. al. (2002), Kammen et. al. (2005), NSF, European Commission, Compustat

Gross domestic expenditures on R&D, by selected region/country: 1995–2006

Current PPP dollars (billions)



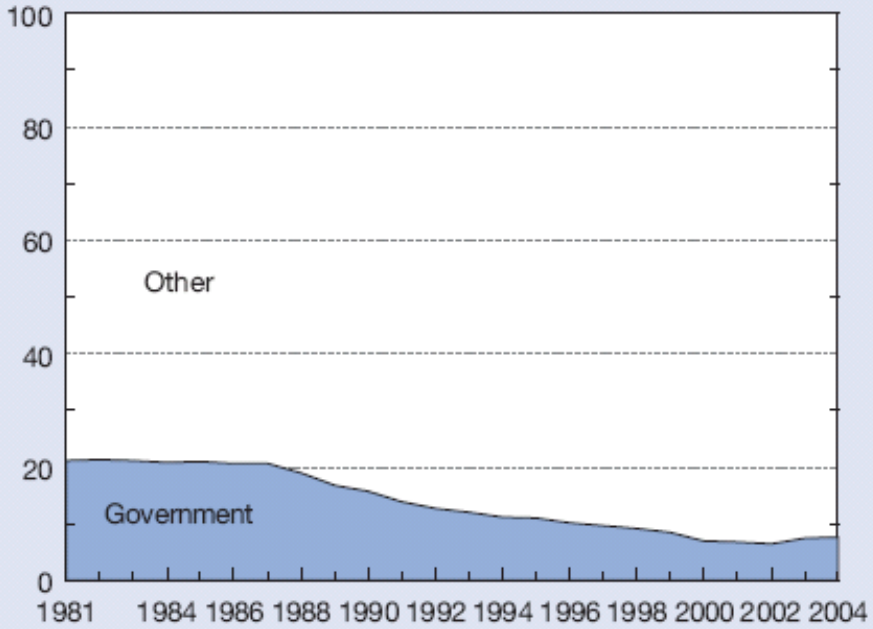
OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTE: European Union (EU)-25 from 1998–2000, EU-27 thereafter.

SOURCE: OECD, Main Science and Technology Indicators 2004–07.

Science and Engineering Indicators 2008

OECD industry R&D, by funding sector: 1981–2004



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SOURCE: OECD, Main Science and Technology Indicators (2006).
See appendix table 4-39.

Science and Engineering Indicators 2008

R&D share of GDP, by region/country/economy: Most recent year
(Percent)

Country/economy	Share
All OECD (2004)	2.25
EU-25 (2005)	1.77
Israel (2005)	4.71
Sweden (2005)	3.86
Finland (2006)	3.51
Japan (2004)	3.18
South Korea (2005)	2.99
United States (2006)	2.57
Germany (2005)	2.51
Taiwan (2004)	2.42
France (2005)	2.13
United Kingdom (2004)	1.73
China (2005)	1.34
Ireland (2005)	1.25
Argentina (2005)	0.46
Mexico (2003)	0.43

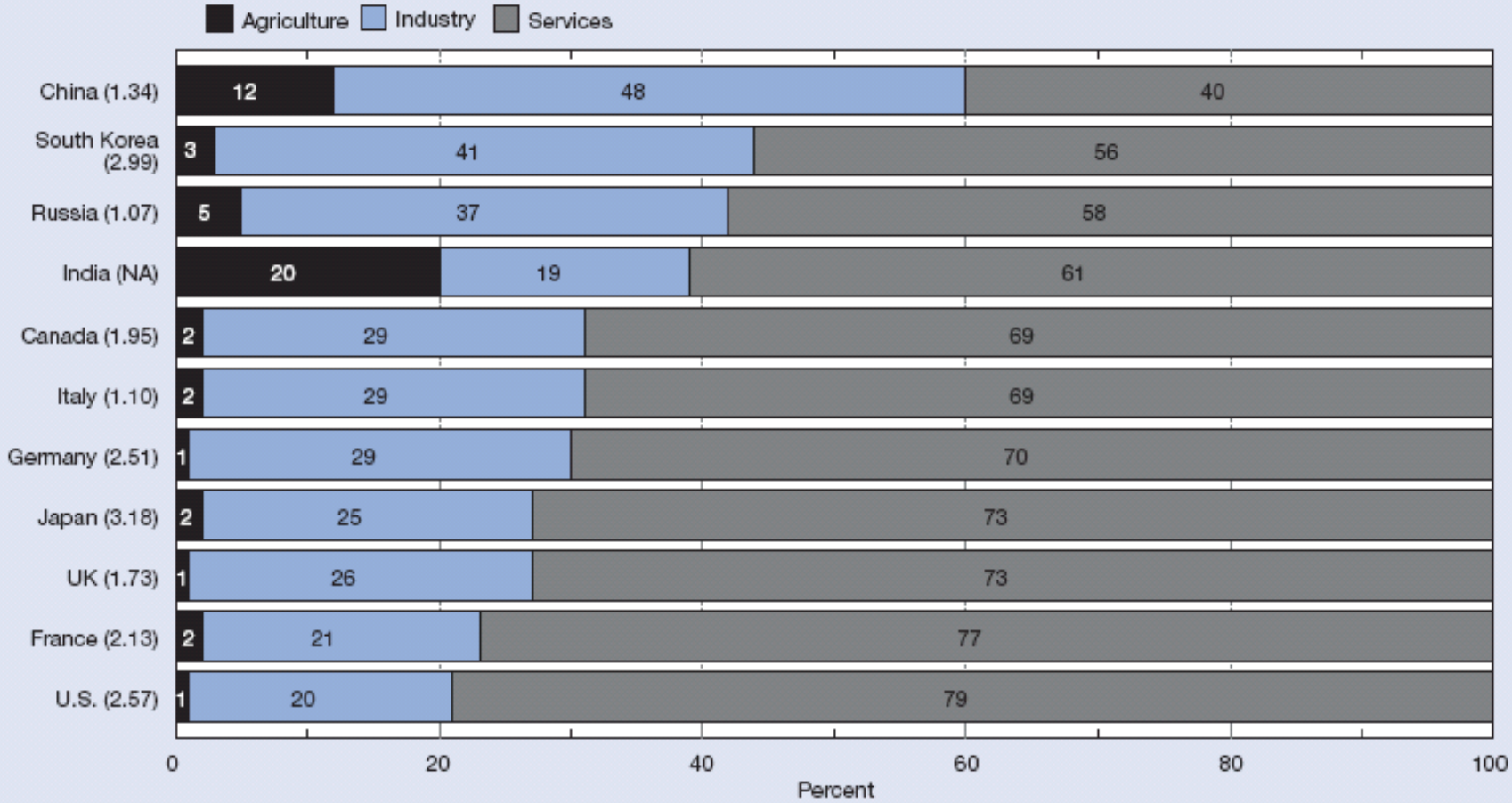
EU = European Union; GDP = gross domestic product;
OECD = Organisation for Economic Co-operation and Development

NOTE: Civilian R&D only for Israel and Taiwan.

SOURCES: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series); and OECD, Main Science and Technology Indicators (2006).

Science and Engineering Indicators 2008

Composition of GDP and R&D/GDP ratio for selected countries, by sector: 2006 or most recent year

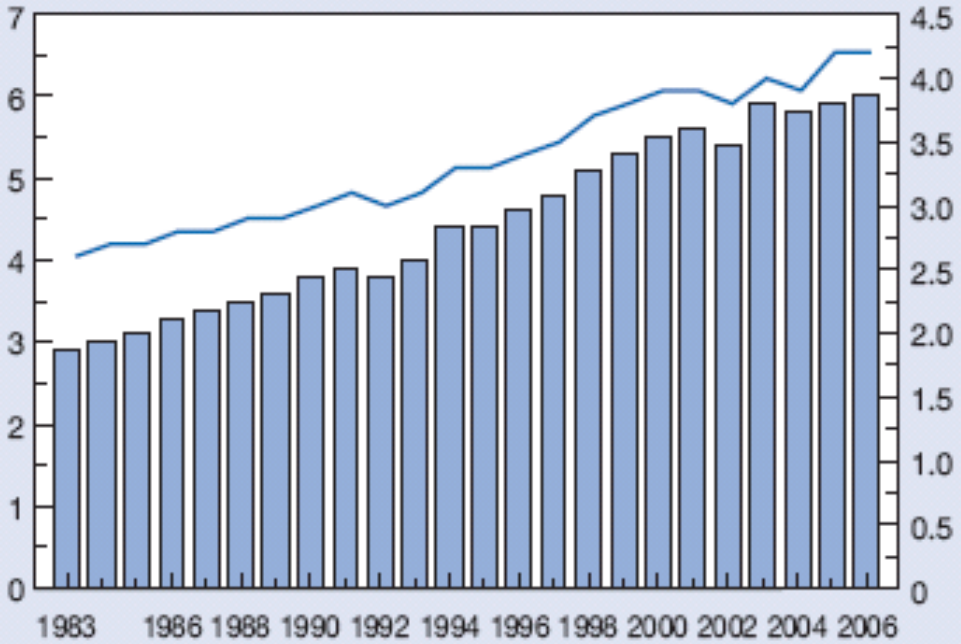


NA = not available
GDP = gross domestic product; UK = United Kingdom

SOURCE: Central Intelligence Agency, *The World Factbook 2007,* http://www.cia.gov/cia/publications/factbook/index.html, accessed 2 March 2007. See table 4-12.

Science and Engineering Indicators 2008

U.S. workforce in S&E occupations: 1983–2006



SOURCE: National Science Foundation, Division of Science Resources Statistics, special tabulations from Bureau of Labor Statistics, Current Population Survey Monthly Outgoing Rotation files (1983–2006).

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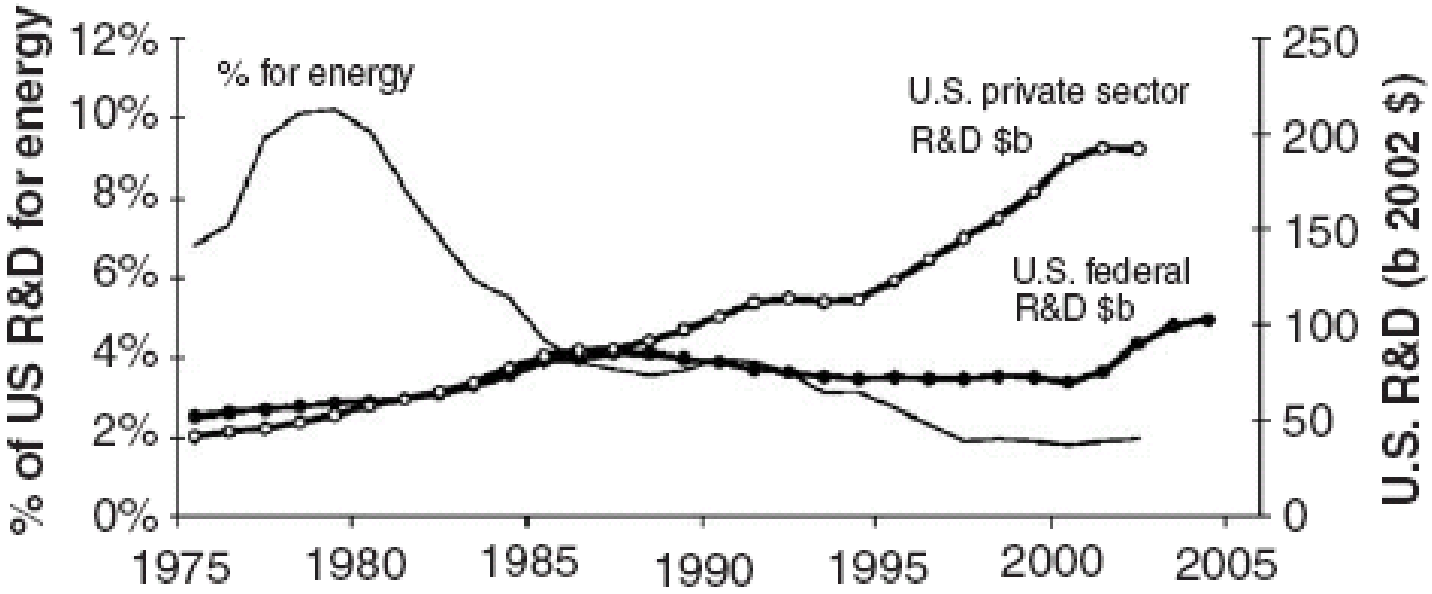
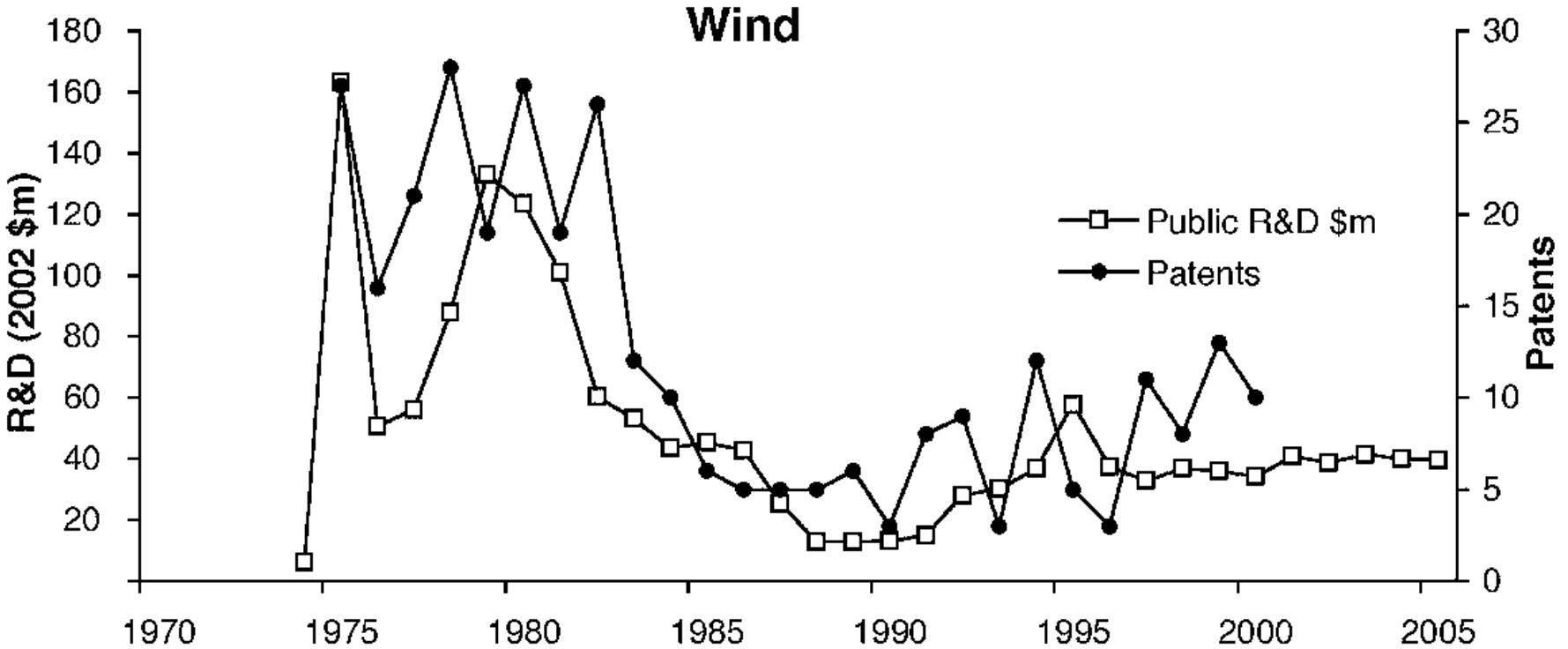
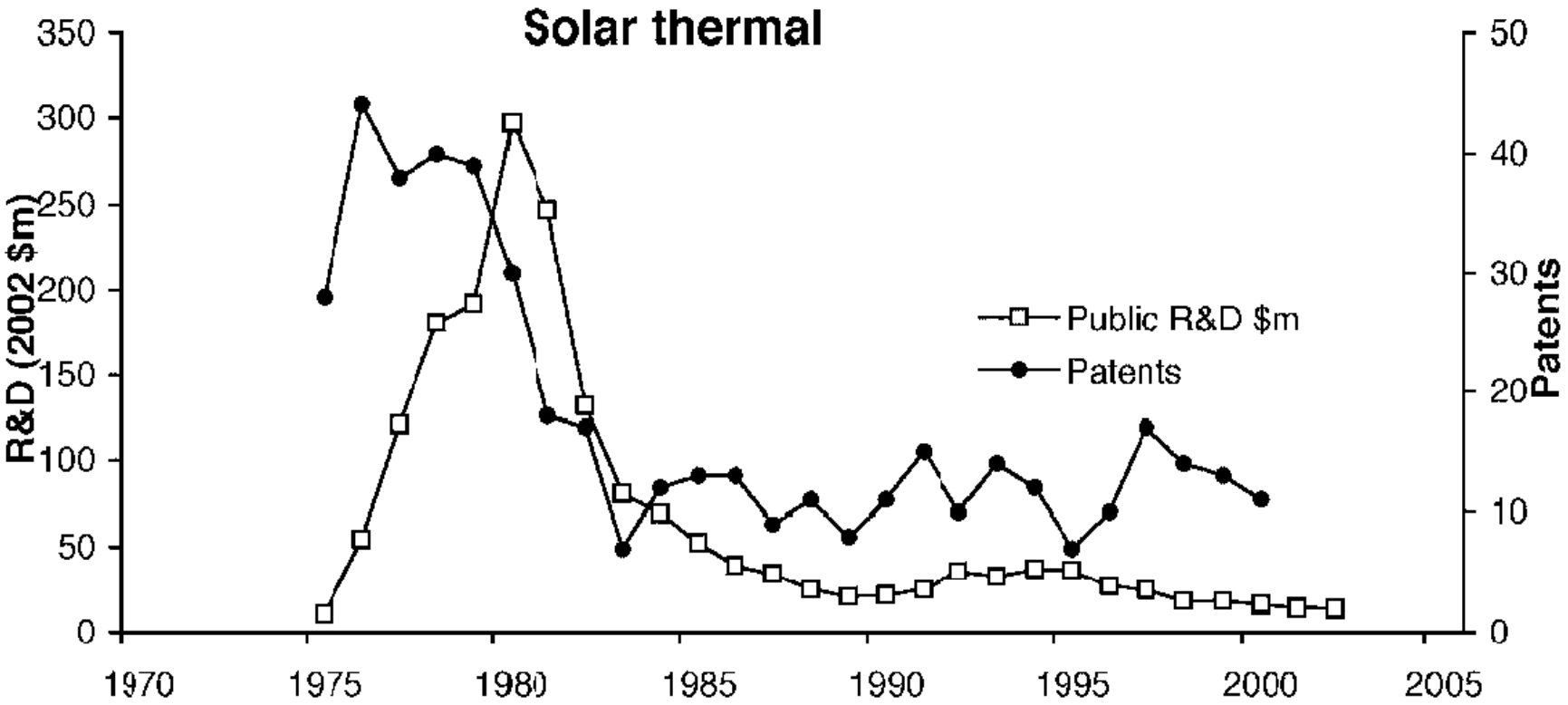
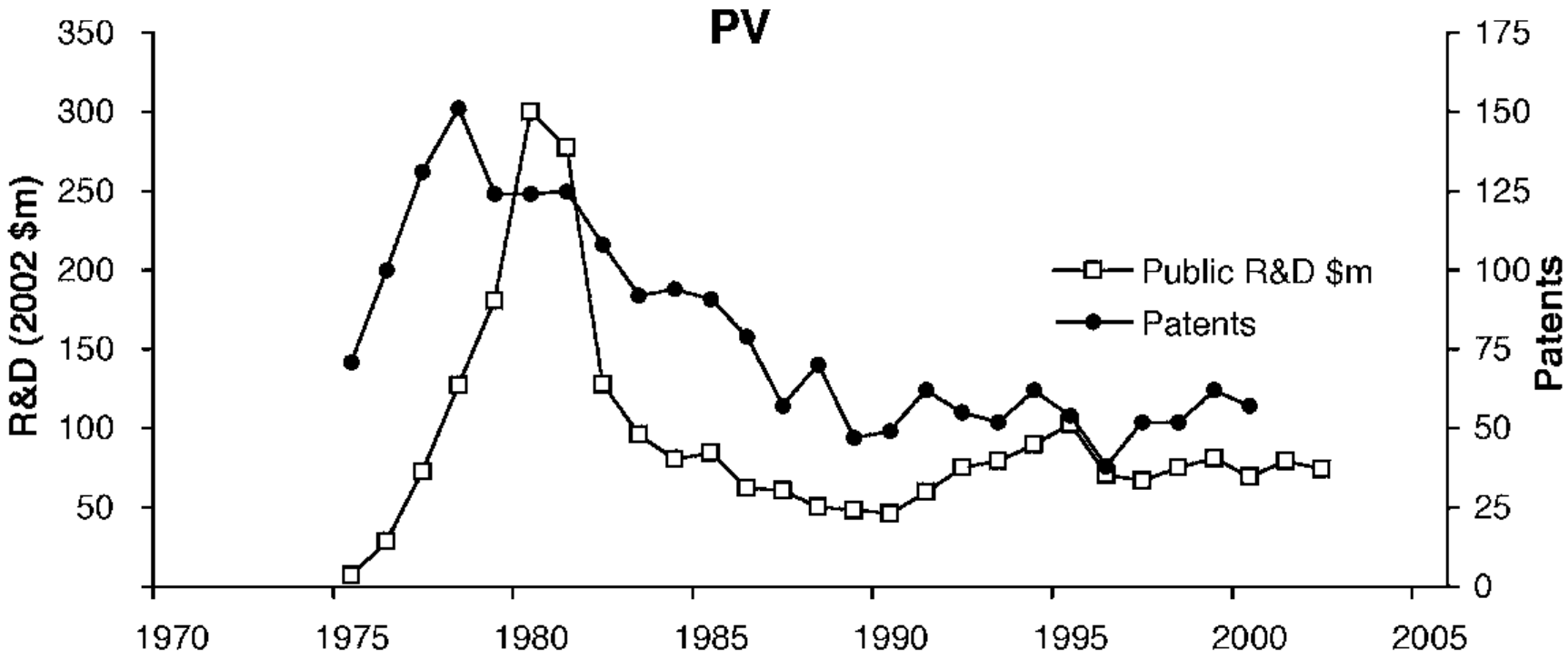
- Positive correlation between stock prices and patenting.


% of US R&D for energy
12%
10%
8%
6%
4%
2%
0%
% for energy
U.S. private sector
R&D $b
U.S. federal
R&D $b
250
200
150
100
50
0
U.S. R&D (b 2002 $)
1975
1980
1985
1990
1995
2000
2005

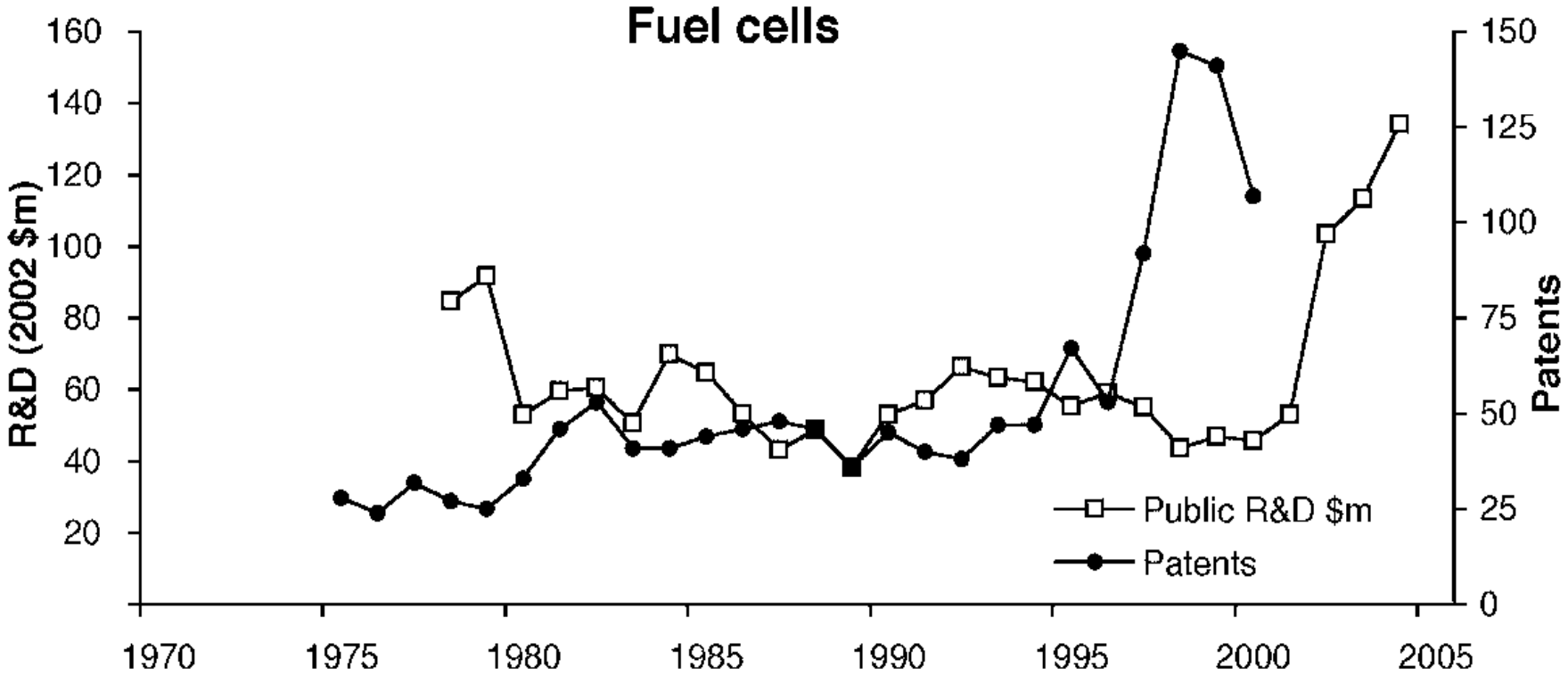

Wind
R&D (2002 $m)
Patents
Public R&D $m
Patents
180
160
140
120
100
80
60
40
20
30
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
2005


Solar thermal
R&D (2002 $m)
Patents
Public R&D $m
Patents
350
300
250
200
150
100
50
0
50
40
30
20
10
0
1970
1975
1980
1985
1990
1995
2000
2005

- *Elasticities:* $1 billion investment in R&D in solar photovoltaics during 1978-85 credited for efficiency increase and resulting cost reductions over the next 20 years.



- Investment and innovation in fuel cells has grown.



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- Production vector of goods/services: $(y_1, ..., y_n)$, where $y_i = y_i(D_i, K_i, L_i)$, D_i - total energy input, $K_i(L_i)$ - capital(labor) input in sector i.

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- $A_0 \rightarrow A_0\gamma \rightarrow A_0\gamma^2 \rightarrow \ldots$ *"Innovation ladder"*

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Interpretation:

- Each innovation gives an invention that results in more efficient use of the non-fossil input to produce energy.

- Value of $t+1$ innovation: $V_{t+1} = G(\overset{+}{\Pi}, \lambda\overset{-}{\phi}(k), \overset{+}{\Gamma})$.

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- Expected profit for innovator: $\Pi = \lambda\phi(k)V_{t+1} - rk$.
- *Profit maximization*: Choose resources devoted to R&D to equate the marginal expected future *private* benefit from innovation to the marginal current private cost.

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- Balanced growth where back-stop technology takes over after a critical level of innovation has taken place.

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- Current resources devoted to R&D may depend negatively on expected future R&D.

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- Check that model generates moments over the sample which resemble features of data not used in calibration (e.g., TFP growth, R&D expenditure, labor-output ratios, etc.).

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- Resulting "efficient" growth rate?

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- *Needed:* Data on private R&D (Beyond *NSF*, *Compustat*).

Sources

- Aghion P., N. Bloom, R. Blundell, R. Griffith, and P. Howitt (2002): Competition and Innovation: An Inverted U Relationship. *NBER* Working Paper.
- Aghion P., and P. Howitt (1992): A Model of Growth Through Creative Destruction. *Econometrica* 60.
- Apollo-Alliance (2004): The Apollo Jobs Report: Good Jobs and Energy Independence, New Energy for America. *The Apollo Alliance.*
- Bental B. and D. Peled (2002): Quantitative Growth Effects of subsidies in a Search Theoretic R&D Model. *Journal of Evolutionary Economics* 12,397-423.
- *European Commission: Directorate-General for Research* (2005): Energy R&D Statistics in the European Research Area. EUR 21453
- Hartley P. and K. Medlock III (2005): Carbon Dioxide: A Limit to Growth? Manuscript.

- Jovanovic, Boyan and Chung-Yi Tse. (2007) "Creative Destruction at the Industry Level" *http://www.econ.nyu.edu/user/jovanovi/Jovanovic-Tse.pdf*
- Kammen D.M. and G.F. Nemet (2005): Reversing the incredible shrinking US energy R&D budget. *Issues in Science and Technology* 22(1), 84-88.
- Klette T.J. and S. Kortum, "Innovating Firms and Aggregate Innovation," *Journal of Political Economy*, 204, 968-1018.
- Kydland, F. and E.C. Prescott, (1982) "Time to Build and Aggregate Fluctuations," *Econometrica.*
- Margolis R.M. and D.M Kammen (1999): Evidence of under-investment in energy R&D in the United States and the impact of federal policy. *Energy Policy* 27, 575-584.
- Wolfe R.M. (2004): Research and Development in Industry. *National Science Foundation.*