Constructing a Price Deflator for R&D: Calculating the Price of Knowledge Investments as a Residual

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Objective of paper

- To construct R&D price index
  - Inform forthcoming capitalisation of R&D
  - Inform European heartsearching about R&D spend (as % of GDP) being flat/falling
- Paper
  - First pass
  - Review existing approaches
  - Implement our approach on UK data
  - Robustness checks
- Basic outline of framework: Edison quote
  - *“The value of an idea lies in the using of it.”*

Model outline

- Two sectors
  - knowledge-producing: gets knowledge for free, but charges mark-up
  - knowledge-using: rents knowledge
- Three factors of production
  - labor,
  - capital,
  - knowledge.
- Production and income flow relationships, knowledge stock accumulation, rental/asset prices

$$N_t = F^N(L_t^N, K_t^N, R_t^N, t); \quad P_t^N N_t = \mu(P_t^L L_t^N + P_t^K K_t^N)$$

$$R_t = N_t + (1-\delta_R)R_{t-1}$$

$$Y_t = F^Y(L_t^Y, K_t^Y, R_t^Y, t); \quad P_t^Y Y_t = P_t^L L_t^Y + P_t^K K_t^Y + P_t^R R_t^Y$$

$$P_t^R = P_t^N(\rho_t + \delta_R)$$

Model outline

$$\Delta \ln P^N = s_N^K \Delta \ln P^K + s_N^L \Delta \ln P^L - \Delta \ln TFP^N$$

$$\Delta \ln P^Y = s_Y^K \Delta \ln P^K + s_Y^L \Delta \ln P^L + s_Y^R \Delta \ln P^R - \Delta \ln TFP^Y$$

$$\Delta \ln TFP^{measured} = \Delta \ln TFP^Y + s_Y^N \Delta \ln TFP^N$$

Method 1: upstream sector

Use data from R&D survey to measure K and L in "innovation" sector, assume μ=1

Problem: TFP in the innovation sector not well understood.

Nests as special case ΔlnTFP=0, μ=1 price index is share-weighted cost based index:

$$\Delta \ln P^N = s_N^K \Delta \ln P^K + s_N^L \Delta \ln P^L$$

But is Δ lnTFP=0 in research sector strong assumption e.g. internet?

So one way is to use assumption on Δ lnTFP, say from hi-tech inds

Model outline

Method 2: downstream sector
Rearrange above

$$\Delta \ln P^R = \left(\frac{\Delta \ln P^Y - s_Y^K \Delta \ln P^K - s_Y^L \Delta \ln P^L + \Delta \ln TFP^Y}{s_Y^R} \right)$$

Aggregate index: which is what we try to estimate

$$\Delta \ln P^{R*} = \sum_{i=1}^{J} \omega_i \left(\frac{\Delta \ln P_i^Y - s_{iY}^K \Delta \ln P_i^K - s_{iY}^L \Delta \ln P_i^L + \Delta \ln TFP_i^Y}{s_{iY}^R} \right)$$

Note that this nests as a special case just downstream prices

$$\Delta \ln P^R = \sum \omega_j \Delta \ln P_j^Y$$

Conceptual issues discussed in paper

- Interpretation:
  - Downstream use of knowledge stock R to produce output: can think of as commercialising knowledge
  - Downstream renting finished knowledge from upstream. Can think of upstream as producing platform, downstream rent versions
- Model similar to Romer, 1990
  - Ideas sector uses knowledge, produces design blueprints
  - Blueprints patented and sold to production sector, who then produces output
  - So value of knowledge is appropriated by ideas sector, production sector commercialises it
- Theory discussion: theory can be extended to
  - Product quality in the downstream sector

UK data set

- Essence of approach: upstream and downstream sectors. So use industry data?
- No. Much R&D is in-house. So, to implement we need to “break” industries into upstream, R&D producing, and downstream, R&D renting
- Data sets
  - BERD: Business Enterprise R&D = surveys own-account R&D spending by firms. Reported for 32 products (~market sector industries).
  - UK EUKLEMS data set (March 2008 release),
    - prices and quantities of output and labor and material input for 72 industries
    - and estimates of capital input and TFP for 23 industries.
  - UK supply-use (IO) tables, for more than 100 industries from 1992 to 2006.
    - allocate own-acc R&D of R&D services industry to other (i.e., downstream) industries using input-output data on sales.
  - VICS: ONS data on capital services at more detailed industry level than EUKLEMS

- Usable final data
  - 29 industry data set, 1981 to 2005. R&D performing industries excluding:
    - the R&D services industry (because its R&D is allocated to purchasing industries using input-output data)
    - software industry and post & telecommunications (problematic TFP data).

Measurement

- Objective: to measure downstream

$$\Delta \ln P_J^R = \frac{\Delta \ln P_J^{G,KLEMS} - s_{Y,G,J}^{\ M} \Delta \ln P_J^M - s_{Y,G,J}^{\ K} \Delta \ln P_J^K - s_{Y,G,J}^{\ L} \Delta \ln P_J^L + \Delta \ln TFP_J^{G,Y}}{s_{Y,G,J}^{\ R}}$$

- What do we have to measure?
  – The downstream materials, labour, capital shares
    - ≠ KLEMS shares, since KLEMS shares are sum of up and downstream
    - So use BERD data to split KLEMS into up- and downstream by subtraction
  – The downstream knowledge capital rental share
    - S(R) downstream = (PrR/PyY).
    - BERD gives us estimate upstream knowledge costs= PnN (measured)
    - Rental price relation between PnN and PrR; τ
    - If upstream marks-up over costs then PnN=μ(PnN, measured)
    - => S(R)=μτ(PnN/PyY). Assume μ and τ. Check robustness
  – Downstream ΔlnTFP(y): econometric method (below)

Summary of shares

- So, shares are

$$s_{Y,G}^{M}=\frac{P^{M}M^{Y}}{P^{G}G^{Y}}=\frac{P^{M}M^{KLEMS}-P^{M}M^{BERD}-P^{N}N^{IO}}{P^{G}G^{KLEMS}}$$

$$s_{Y,G}^{L}=\frac{P^{L}L^{Y}}{P^{G}G^{Y}}=\frac{P^{L}L^{KLEMS}-P^{L}L^{BERD}}{P^{G}G^{KLEMS}}$$

$$s_{Y,G}^{R}=\frac{P_{t}^{R}R^{Y}}{P^{G}G^{Y}}=\tau\mu\frac{\left(P_{t}^{N}N^{BERD}+P_{t}^{N}N^{IO}\right)}{P^{G}G^{KLEMS}};\tau=\frac{(\rho+\delta_{R})(1+\Delta R^{Y,OA}/R^{Y,OA})}{\left(\Delta R^{Y,OA}/R^{Y,OA}+\delta_{R}\right)}$$

$$s_{Y,G}^{K}=1-s_{Y,G}^{M}-s_{Y,G}^{L}-s_{Y,G}^{R}$$

TFP in downstream

- TFP in downstream unobserved because measured TFP is the whole industry i.e. both up and downstream TFP.
- Theory (Domar, 61) suggests in long run

$$\Delta \ln TFP^{measured} = \Delta \ln TFP^{Y} + s_N^Y \Delta \ln TFP^{N}$$

- Thus we run regression, pooled data 1985-95 and 1995-2005

$$\Delta \ln TFP_{it}^{KLEMS} = a + b \cdot s_{N,it}^{Y,G} + e_{it}$$

- And use estimated “a” as estimate of $\Delta \ln TFP^{Y}$
- NB. Looks like a rate of return to R&D regression

Thus we compute

- For each industry J

$$\Delta \ln P_J^R = \frac{\Delta \ln P_J^{G,KLEMS} - s_{Y,G,J}^{M} \Delta \ln P_J^M - s_{Y,G,J}^{K} \Delta \ln P_J^K - s_{Y,G,J}^{L} \Delta \ln P_J^L + \theta_J \Delta \ln TFP_J^{G,KLEMS}}{s_{Y,G,J}^{R}}$$

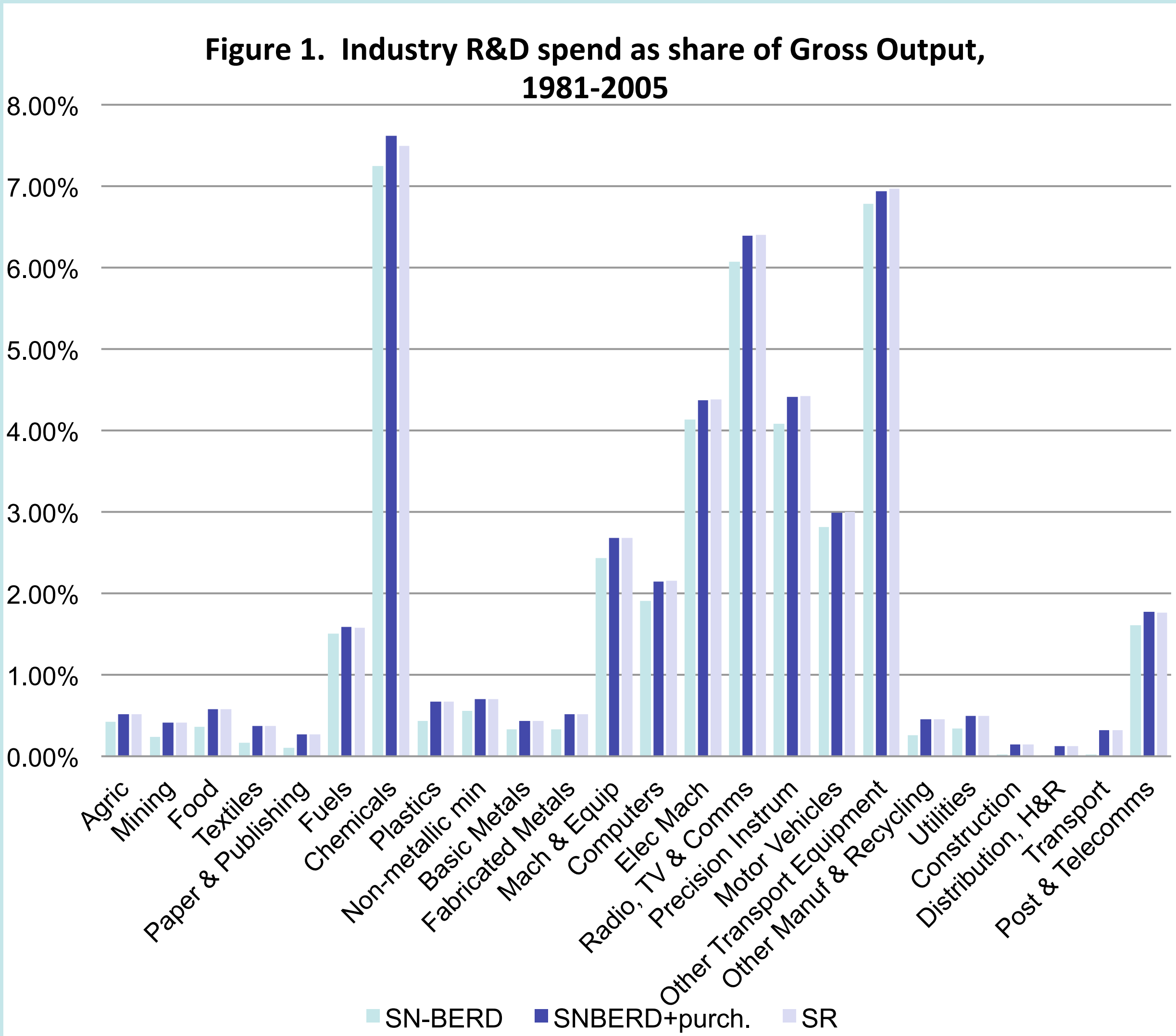
Where θ=share of total ΔlnTFP in downstream.

Then we compute an overall index

$$\Delta \ln P^R = \sum_{j=1}^{J} \omega_j^{P^R} \left(\Delta \ln P_J^{R} \right)$$

- Robustness checks to assumed values, τ,μ, a (hat) etc.

Alternative shares of knowledge spend industry gross output

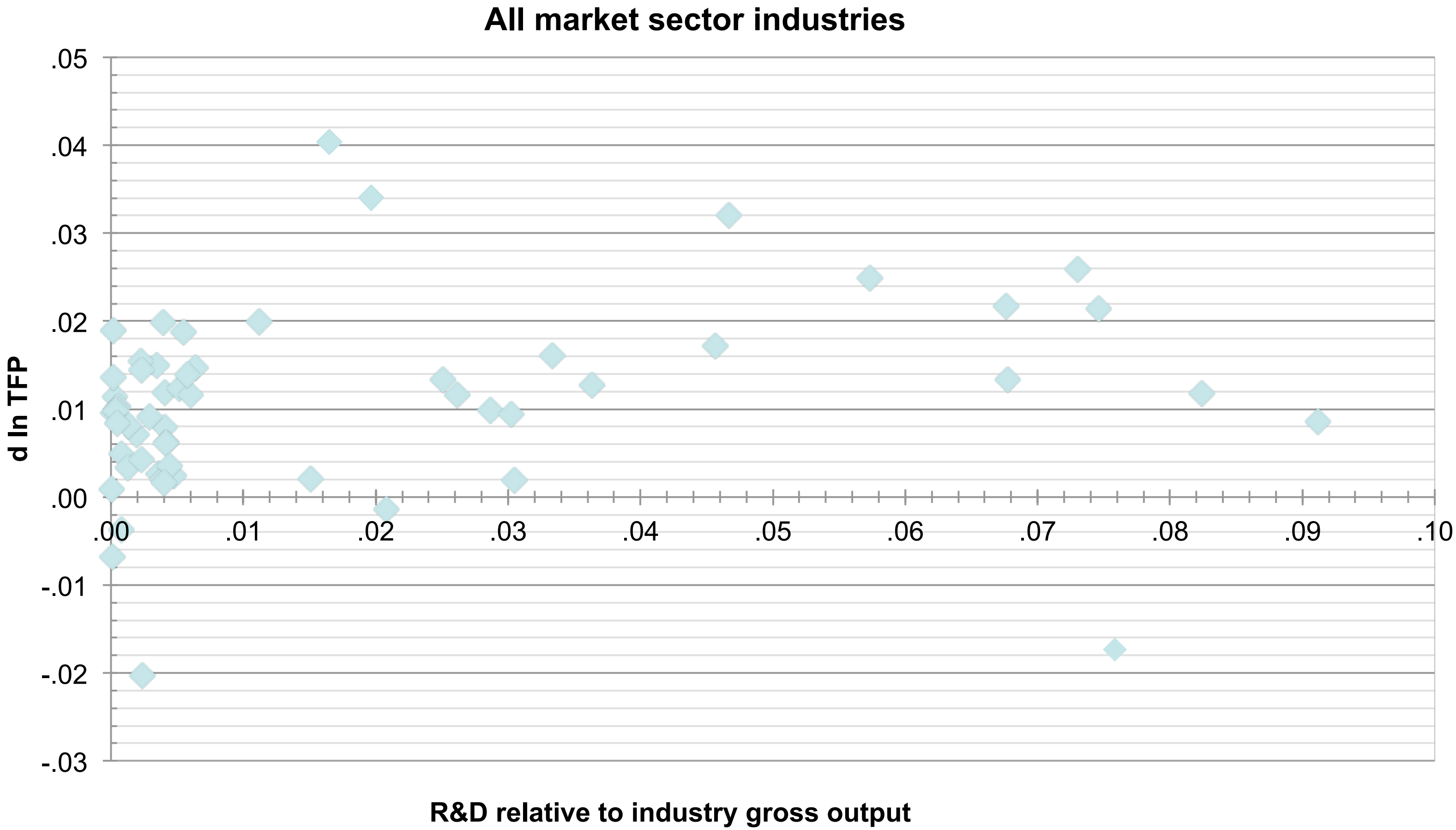


sN-BERD: own-account PnN as share of GO

sN-BERD +purch: own-account plus allocated from PnN in R&D services,, as share of GO

sR: knowledge rentals as share of GO

Mean ΔlnTFP(J) & Mean sN(J): All market sector industries



Regression: $\Delta \ln TFP_{it}^{KLEMS} = a + b \cdot s_{N,it}^{Y,G} + e_{it}$

	Estimation by Random Effects (Robust standard errors in parentheses)				
	Dependent variable: $\Delta \ln TFP_{G,i}^{measured}$				
	(1)	(2)	(3)	(4)	(5)
Independent variables	μ=1.00	μ=1.15	μ=1.15	μ=1.15	μ=1.15
Constant	.0091***	.0091***	.0107***	.0089***	.0080***
	(.0017)	(.0017)	(.0019)	(.0015)	(.0019)
$s_{G,i}^{N}$	.1431***	.1244***	.1318***	.2258***	.2423***
	(.0505)	(.0439)	(.0482)	(.0482)	(.0544)
1995-2005 dummy	--	--	-.0040*	--	.0002
			(.0023)		(.0030)
$s_{G,i}^{N}$ * 1995–2005 dummy	--	--	--	-.1852***	-.2222***
				(.0541)	(.0771)
Memos:					
$\hat{\theta}$: share of downst ΔlnTFP in total ΔlnTFP	.73	.73	.70	.71	.76
$\hat{\theta}_1$ (1985 - 1995)			.77	.63	.57
$\hat{\theta}_2$ (1995 - 2005)			.63	.83	.94

Note--Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

$$s_N^{Y,G} = P^N N / P^G G = \left(\mu\left(P^L L^{BERD} + P^K K^{BERD} + P^M M^{BERD} + P^N N^{IO}\right)\right) / P^G G$$

Results

1985-2005	ΔlnP^N (*(%pa)*	$\Delta lnTFP^N$ *(%pa)*	*Contrib to GDP from R&D (%pa)*	*Share of total* $\Delta lnTFP$ *due to* $\Delta lnTFP^N$
Method:				
Input cost	+4.0	0 (by assumption)	0.03	0 (by assumption)
Residual	-7.5	12.4	0.25	27%

Memo: GDP deflator = 3.5, R&D weighted output price change = 2.1

Summary

- First pass attempt to measure R&D price from price of downstream R&D users
- Theory suggests needs assumptions on
  - μ = Innovator mark up
  - τ = relation $P^N N$ and $P^R R$
  - Downstream ΔlnTFP = $\Delta \ln TFP^Y$
- Central estimates:
  - UK R&D prices fall by around 7.5%pa 1985-05.
    - Compare with GDP deflator +3.5%
    - R&D input cost deflator +4%
  - Contribution of R&D to market sector GDP growth is
    - With this fall 0.25% pa
    - With GDP deflator 0.03%pa
- Future work to further investigate sensitivity to
  - Innovator mark up
  - Industry inclusion
  - $\Delta \ln TFP^Y$

spares

Weights

Memo:

We estimate the contribution of change in R&D rental price to industry GO price:

$$s^R_{G,i,t}\Delta\ln P^R_i = \Delta\ln P^{GO}_{i,t} - (1-s^R_{G,i,t})\Delta\ln C^{measured}_{G,i,t} + \theta\,\Delta\ln TFP^{measured}_{G,i,t}$$

Then we obtain overall contribution by aggregating, using Domar weights:

$$s^R_Y\Delta\ln P^R = \sum_{i=1,J}\frac{GO_i}{GVA_S}\, s^R_{G,i}\Delta\ln P^R_i$$

Since:

$$s^R_Y = \tau P^N N / GVA_S$$

Then:

$$\Delta\ln P^R = \sum_{i=1,J}\frac{GO_i}{\tau P^N N}\, s^R_{G,i}\Delta\ln P^R_i \;\rightarrow\; \Delta\ln P^R = \sum_{i=1,J}\frac{GO_i}{P^N N}\, s^N_{G,i}\Delta\ln P^R_i$$

So ω is the industry share of $P^N N$

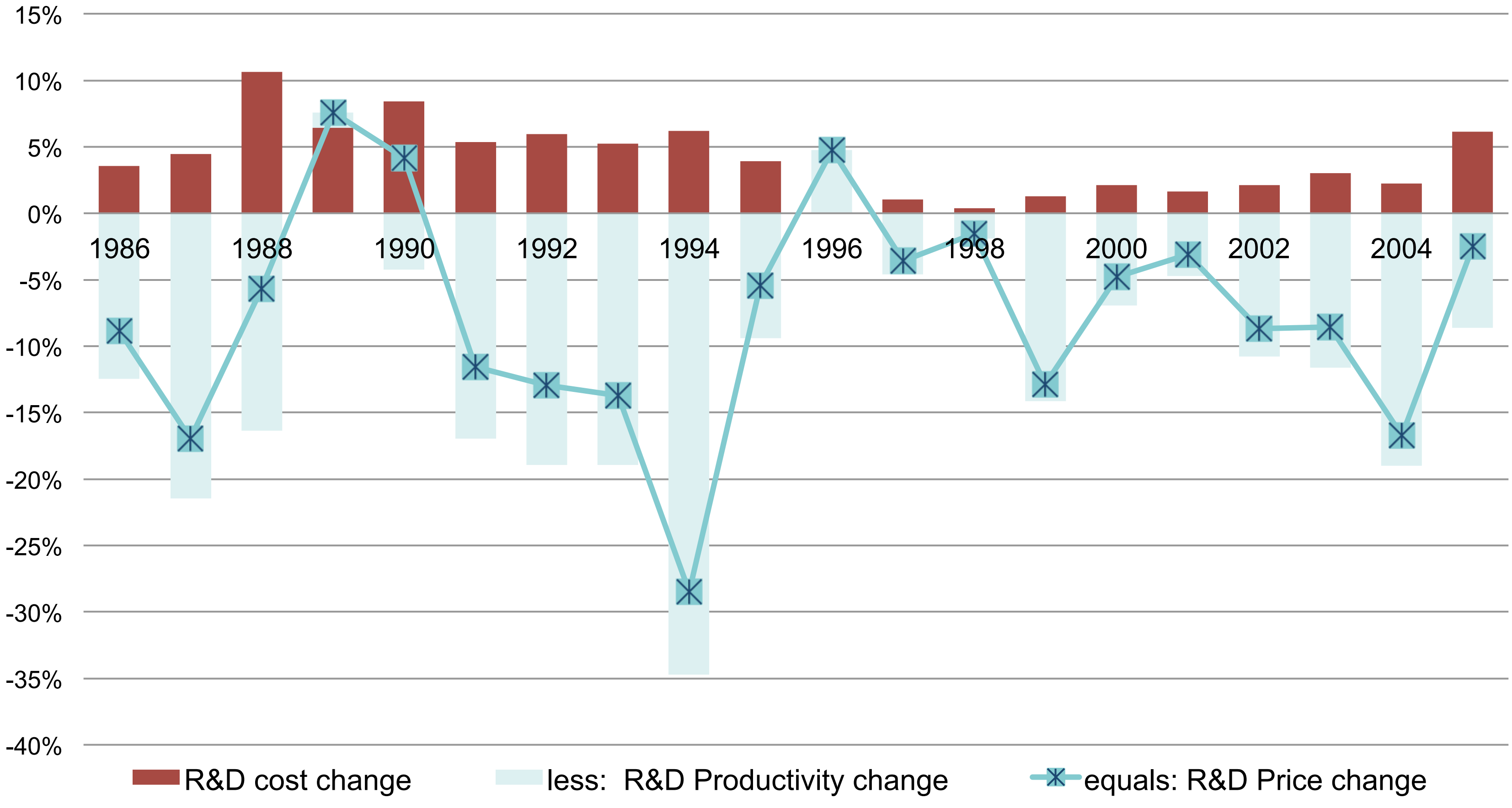
Table 3. R&D price change under alternative assumptions for R&D productivity change $(\Delta \ln TFP^N)$.

	$\Delta \ln TFP^N =$				Memos:	
Period	0 $[\theta = 1]$	$\Delta \ln TFP^Y$ $[1/(1+s^R_{i,G})]$	Estimated $[\theta = \hat{\theta}]$	Estimated $[\theta = \hat{\theta}_1, \hat{\theta}_2]$	Column (3) with $\mu = 1.3$	R&D weighted output price change
	(1)	(2)	(3)[1,2]	(4)[1,3]	(5)	(6)
1. 1985-1995	6.0	4.2	-9.2	-14.7	-8.4	3.6
2. 1995-2005	2.0	.8	-5.8	-3.0	-5.5	.7
3. 1985-2005	4.0	2.5	-7.5	-8.8	-7.0	2.1

Notes—Recall $\theta = \Delta \ln TFP^Y / \Delta \ln TFP^{measured}$ and $\Delta \ln TFP^Y$ is downstream productivity change. Columns (1) through (4) use $\mu = 1.15$

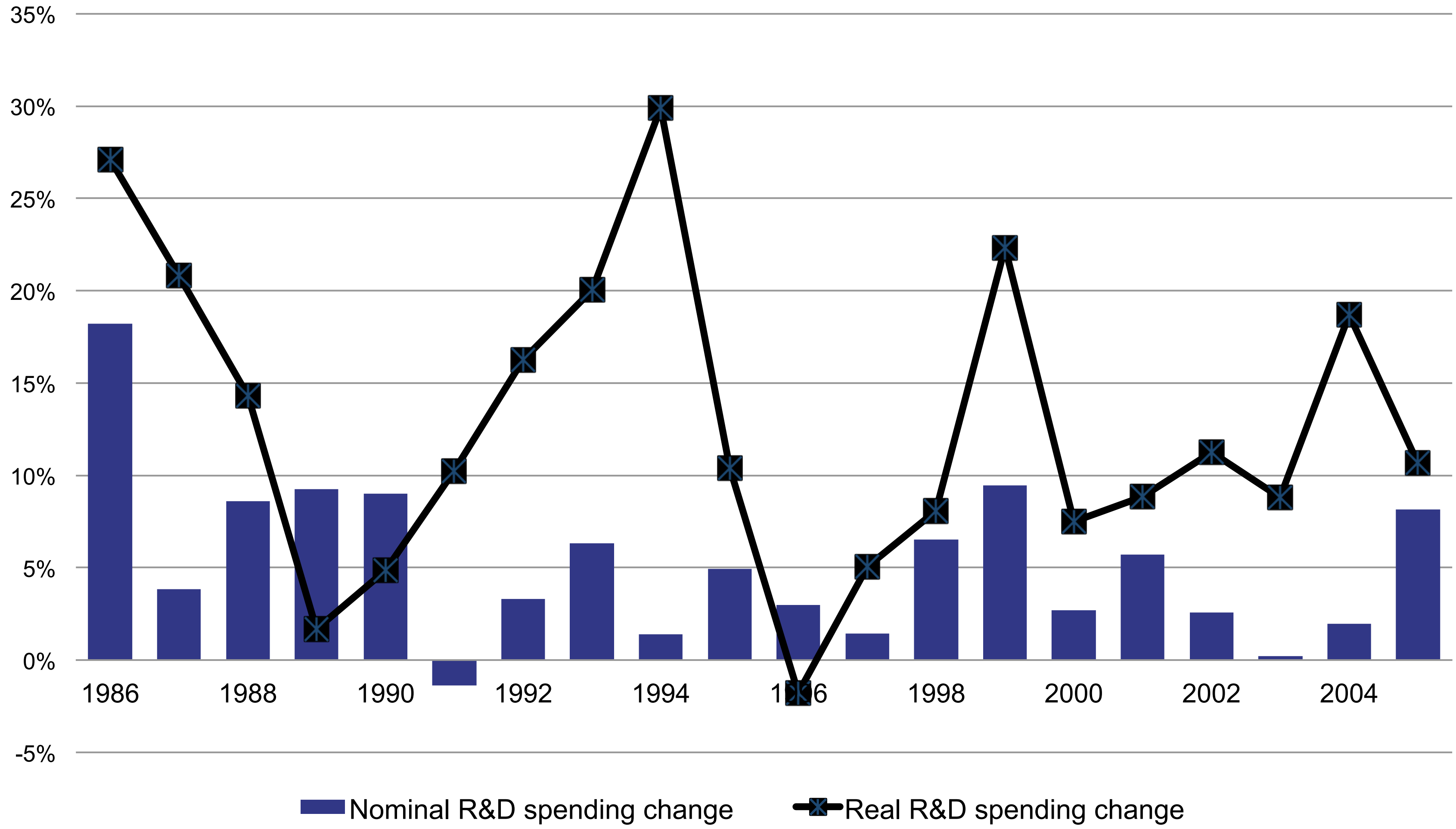
1. Industries with problematic TFP estimates as well as those in the lower R&D quartile use $\Delta \ln TFP^N = \Delta \ln TFP^Y$
2. The estimated $\hat{\theta}$ is from column 2 of table 2.
3. The estimated $\hat{\theta}_1, \hat{\theta}_2$ are from column 4 of table 2.

Results



15%
10%
5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
R&D cost change
less: R&D Productivity change
equals: R&D Price change

Results



35%
30%
25%
20%
15%
10%
5%
0%
-5%
1986
1988
1990
1992
1994
1998
2000
2002
2004
Nominal R&D spending change
Real R&D spending change

Robustness: θ

Table 4. UK R&D price change for a range of values of θ, 1985-2005					
1. θ if $s^R_{G,i} > .003$	.60	.70	.75	.80	.90
2. $\Delta \ln P^N$	-13.0	-8.8	-6.7	-4.6	-.4
3. $\Delta \ln N$ (or g)	18.3	14.1	12.0	9.9	5.6
4. $\overline{\theta}$, all industries	.76	.82	.85	.88	.94

Note—Figures are calculated assuming $\mu = 1.15$, $\tau = 1$. The variation in θ applies to productivity of major R&D performers only.

Effect of different Pr on growth accounting results with R&D capitalised

Table 5. Growth in output per hour, TFP, and R&D stocks, UK market sector

	1985 to 2005	1985 to 1995	1995 to 2005
1. Output per hour, R&D capitalized	2.9	3.0	2.8
1a Without R&D capitalization	2.7	2.7	2.6
1b Difference due to capitalization[1]	.22	.30	.14
1c Contrib. of R&D deflator	.16	.21	.12
2. TFP, R&D capitalized	2.2	2.2	2.1
2a Without R&D capitalization	2.2	2.3	2.1
2b Difference due to capitalization[2]	-.05	-.06	-.05
3. Real stocks of R&D assets	12.7	14.2	11.1
3a Contrib. of R&D capital deepening[3]	.25	.33	.17

Note—Growth rates are calculated using log differences. Italicized entries are percentage points.
1. Line 1 less line 1a.
2. Line 2 less line 2a.
3. Contribution to the growth in output per hour, line 1.

Downstream knowledge rental payments, $P^R R$?

- Assume value of new knowledge created in the upstream sector

$$P^N N \equiv \mu\left[\left(P^L L^{BERD} + P^K K^{BERD} + P^M M^{BERD}\right) + P^N N^{IO}\right]$$

- To convert $P^N N$ to $P^R R$, use rental and PIM

$$P_t^R R^{Y,OA} = P_t^N N^{BERD}(\rho_t + \delta_R)\frac{R^{Y,OA}}{N^{BERD}} \qquad R_t = N_t + (1-\delta_R)R_{t-1}$$

- To give

$$P^R R^{Y,OA} = \frac{P^N N^{BERD}(\rho + \delta_R)(1 + \Delta R^{Y,OA}/R^{Y,OA})}{\left(\Delta R^{Y,OA}/R^{Y,OA} + \delta_R\right)}$$

$$= \tau\left(P^N N^{BERD}\right), \qquad where\ \tau = \frac{(\rho + \delta_R)(1 + \Delta R^{Y,OA}/R^{Y,OA})}{\left(\Delta R^{Y,OA}/R^{Y,OA} + \delta_R\right)}$$

Mean lnTFP(J) & Mean sN(J): Excl. outliers, nonperformers, and lowest R&D quartile, 2 productivity episodes