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 \( \mu=1 \)

Problem: TFP in the innovation sector not well understood.

Nests as special case \( \Delta \ln TFP=0, \mu=1 \) 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 \( \Delta \ln TFP=0 \) in research sector strong assumption e.g. internet?

So one way is to use assumption on \( \Delta \ln TFP \), say from hi-tech inds
Model outline

Method 2: downstream sector
Rearrange above

\[ \Delta \ln P^R = \left( \frac{\Delta \ln P^Y - s^K_Y \Delta \ln P^K - s^L_Y \Delta \ln P^L + \Delta \ln TFP^Y}{s^R_Y} \right) \]

Aggregate index: which is what we try to estimate

\[ \Delta \ln P^{R*} = \sum_{i=1}^{J} \omega_i \left( \frac{\Delta \ln P^Y_i - s^K_{iY} \Delta \ln P^K_i - s^L_{iY} \Delta \ln P^L_i + \Delta \ln TFP^Y_i}{s^R_{iY}} \right) \]

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
  - 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

\[ \Delta \ln P_j^R = \frac{\Delta \ln P_{jG}^{G,KLEMS} - s_{Y,G,J}^M \Delta \ln P_j^M - s_{Y,G,J}^K \Delta \ln P_j^K - s_{Y,G,J}^L \Delta \ln P_j^L + \Delta \ln TFP_{jG,Y}}{s_{Y,G,J}^R} \]

• 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 \( PrR; \tau \)
    • If upstream marks-up over costs then \( PnN=\mu(PnN, \text{measured}) \)
    • \( \Rightarrow S(R)=\mu\tau(PnN/PyY) \). Assume \( \mu \) and \( \tau \). Check robustness
  – Downstream \( \Delta \ln TFP(y) \): econometric method (below)
Summary of shares

- So, shares are

\[
S_{Y,G}^M = \frac{P^M M^Y}{P^G G^Y} = \frac{P^M M^{KLEMS} - P^M M^{BERD} - P^N N^{IO}}{P^G G^{KLEMS}}
\]

\[
S_{Y,G}^L = \frac{P^L L^Y}{P^G G^Y} = \frac{P^L L^{KLEMS} - P^L L^{BERD}}{P^G G^{KLEMS}}
\]

\[
S_{Y,G}^R = \frac{P_t^R R^Y}{P^G G^Y} = \tau \mu \left( P_t^N N^{BERD} + P_t^N N^{IO} \right) \frac{P^G G^{KLEMS}}{P^G G^{KLEMS}};
\tau = (\rho + \delta_R)(1 + \Delta R_{Y,OA}^{Y,OA} / R_{Y,OA}^{Y,OA})
\]

\[
S_{Y,G}^K = 1 - S_{Y,G}^M - S_{Y,G}^L - S_{Y,G}^R
\]
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

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

• 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 $\theta =$ share of total $\Delta \ln TFP$ in downstream.

Then we compute an overall index

\[
\Delta \ln P^R = \sum_{j=1}^J \omega_j^{R^R} \left( \Delta \ln P_j^R \right)
\]

- Robustness checks to assumed values, $\tau, \mu, a$ (hat) etc.
Alternative shares of knowledge spend industry gross output

Figure 1. Industry R&D spend as share of Gross Output, 1981-2005

**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 $\Delta \ln TFP(J)$ & Mean $sN(J)$: All market sector industries

R&D relative to industry gross output

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)

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variable:</strong> ( \Delta \ln TFP_{G,i}^{measured} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Independent variables</strong></td>
<td>( \mu = 1.00 )</td>
<td>( \mu = 1.15 )</td>
<td>( \mu = 1.15 )</td>
<td>( \mu = 1.15 )</td>
<td>( \mu = 1.15 )</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>( .0091^{***} )</td>
<td>( .0091^{***} )</td>
<td>( .0107^{***} )</td>
<td>( .0089^{***} )</td>
<td>( .0080^{***} )</td>
</tr>
<tr>
<td></td>
<td>( (.0017) )</td>
<td>( (.0017) )</td>
<td>( (.0019) )</td>
<td>( (.0015) )</td>
<td>( (.0019) )</td>
</tr>
<tr>
<td>( s_{G,i}^{N} )</td>
<td>( .1431^{***} )</td>
<td>( .1244^{***} )</td>
<td>( .1318^{***} )</td>
<td>( .2258^{***} )</td>
<td>( .2423^{***} )</td>
</tr>
<tr>
<td></td>
<td>( (.0505) )</td>
<td>( (.0439) )</td>
<td>( (.0482) )</td>
<td>( (.0482) )</td>
<td>( (.0544) )</td>
</tr>
<tr>
<td><strong>1995-2005 dummy</strong></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>-.0040*</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( (.0023) )</td>
<td>( (.0030) )</td>
</tr>
<tr>
<td>( s_{G,i}^{N} ) * 1995–2005 dummy</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>-.1852***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( (.0541) )</td>
</tr>
<tr>
<td><strong>Memos:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \hat{\theta} ): share of downst ( \Delta \ln TFP ) in total ( \Delta \ln TFP )</td>
<td>.73</td>
<td>.73</td>
<td>.70</td>
<td>.71</td>
<td>.76</td>
</tr>
<tr>
<td>( \hat{\theta}_1 ) (1985 - 1995)</td>
<td>.77</td>
<td>.77</td>
<td>.63</td>
<td>.57</td>
<td></td>
</tr>
<tr>
<td>( \hat{\theta}_2 ) (1995 - 2005)</td>
<td></td>
<td></td>
<td>.63</td>
<td>.83</td>
<td>.94</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>1985-2005</th>
<th>$\Delta \ln P^N$ (%pa)</th>
<th>$\Delta \ln TFP^N$ (%pa)</th>
<th>Contrib to GDP from R&amp;D (%pa)</th>
<th>Share of total $\Delta \ln TFP$ due to $\Delta \ln TFP^N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input cost</td>
<td>+4.0</td>
<td>0 (by assumption)</td>
<td>0.03</td>
<td>0 (by assumption)</td>
</tr>
<tr>
<td>Residual</td>
<td>-7.5</td>
<td>12.4</td>
<td>0.25</td>
<td>27%</td>
</tr>
</tbody>
</table>

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
  – $\mu$ = Innovator mark up
  – $\tau$ = relation $P^N$ and $P^R$
  – Downstream $\Delta\ln TFP = \Delta\ln TFP^Y$
• 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:

\[ s^R_{G,i,t} \Delta \ln P^R_i = \Delta \ln P^{GO}_{i,t} - (1 - s^R_{G,i,t}) \Delta \ln C_{G,i,t}^{measured} + \theta \Delta \ln TFP_{G,i,t}^{measured} \]

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 \( \omega \) is the industry share of \( P^NN \)
Table 3. R&D price change under alternative assumptions for R&D productivity change \((\Delta \ln TFP^N)\).

<table>
<thead>
<tr>
<th>Period</th>
<th>(\Delta \ln TFP^Y) ([\theta = 1])</th>
<th>Estimated (\theta = \theta_1)</th>
<th>Estimated (\theta = \theta_1, \theta_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1985-1995</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)(^{1,2})</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>4.2</td>
<td>-9.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-14.7</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>-8.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>2. 1995-2005</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)(^{1,2})</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>.8</td>
<td>-5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-3.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>-5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.7</td>
</tr>
<tr>
<td>3. 1985-2005</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)(^{1,2})</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>2.5</td>
<td>-7.5</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>-8.8</td>
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<td></td>
<td>-7.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.1</td>
</tr>
</tbody>
</table>

\(\Delta \ln TFP^N =\) Column (3) with \(\mu = 1.3\) \(\text{ R&D weighted output price change}\), Memos:

Notes—Recall \(\theta = \Delta \ln TFP^Y / \Delta \ln TFP^\text{measured}\) 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 \(\Delta \ln TFP^Y = \Delta \ln TFP^Y\)
2. The estimated \(\theta\) is from column 2 of table 2.
3. The estimated \(\theta_1, \theta_2\) are from column 4 of table 2.
Results

R&D cost change
less: R&D Productivity change
equals: R&D Price change
Robustness: $\theta$

Table 4. UK R&D price change for a range of values of $\theta$, 1985-2005

<table>
<thead>
<tr>
<th></th>
<th>$\theta$ if $s_{G,i}^R &gt; .003$</th>
<th>.60</th>
<th>.70</th>
<th>.75</th>
<th>.80</th>
<th>.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Delta \ln P^N$</td>
<td>-13.0</td>
<td>-8.8</td>
<td>-6.7</td>
<td>-4.6</td>
<td>-.4</td>
</tr>
<tr>
<td>2</td>
<td>$\Delta \ln N$ (or g)</td>
<td>18.3</td>
<td>14.1</td>
<td>12.0</td>
<td>9.9</td>
<td>5.6</td>
</tr>
<tr>
<td>3</td>
<td>$\bar{\theta}$, all industries</td>
<td>.76</td>
<td>.82</td>
<td>.85</td>
<td>.88</td>
<td>.94</td>
</tr>
</tbody>
</table>

Note—Figures are calculated assuming $\mu = 1.15$, $\tau = 1$. The variation in $\theta$ 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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Output per hour, R&amp;D capitalized</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a Without R&amp;D capitalization</td>
<td>2.7</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>1b Difference due to capitalization$^1$</td>
<td>.22</td>
<td>.30</td>
<td>.14</td>
</tr>
<tr>
<td>1c Contrib. of R&amp;D deflator</td>
<td>.16</td>
<td>.21</td>
<td>.12</td>
</tr>
<tr>
<td><strong>2. TFP, R&amp;D capitalized</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a Without R&amp;D capitalization</td>
<td>2.2</td>
<td>2.3</td>
<td>2.1</td>
</tr>
<tr>
<td>2b Difference due to capitalization$^2$</td>
<td>-.05</td>
<td>-.06</td>
<td>-.05</td>
</tr>
<tr>
<td><strong>3. Real stocks of R&amp;D assets</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a Contrib. of R&amp;D capital deepening$^3$</td>
<td>12.7</td>
<td>14.2</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>.25</td>
<td>.33</td>
<td>.17</td>
</tr>
</tbody>
</table>

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, $P^{RR}$?

- Assume value of new knowledge created in the upstream sector
  \[ P^N N = \mu \left[ (P^L L^{BERD} + P^K K^{BERD} + P^M M^{BERD}) + P^N N^{IO} \right] \]

- To convert $P^NN$ to $P^{RR}$, use rental and PIM
  \[ P^R R_{Y,OA} = P^N N^{BERD} (\rho + \delta_R) \frac{R^Y_{Y,OA}}{N^{BERD}} \]
  \[ R_t = N_t + (1 - \delta_R) R_{t-1} \]

- To give
  \[ P^R R_{Y,OA} = \frac{P^N N^{BERD} (\rho + \delta_R)(1 + \Delta R^Y_{Y,OA} / R^Y_{Y,OA})}{(\Delta R^Y_{Y,OA} / R^Y_{Y,OA} + \delta_R)} \]

  \[ = \tau \left( P^N N^{BERD} \right), \quad \text{where} \quad \tau = \frac{(\rho + \delta_R)(1 + \Delta R^Y_{Y,OA} / R^Y_{Y,OA})}{(\Delta R^Y_{Y,OA} / R^Y_{Y,OA} + \delta_R)} \]
Mean $\ln TFP(J)$ & Mean $sN(J)$: Excl. outliers, nonperformers, and lowest R&D quartile, 2 productivity episodes

Excl. outliers, nonperformers, and lowest R&D quartile

R&D relative to industry gross output

- 1985 to 1995
- 1995 to 2005