THE IMPACT OF R&D ON THE SINGAPORE ECONOMY: A TIME SERIES ANALYSIS

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OVERVIEW

- Current empirical literature on R&D’s contribution to economic growth largely focuses on:
  - Research at the firm or industry level (Australian Industry Commission, 1995; Link and Siegel, 2003)
  - Advanced countries where intensity of R&D expenditure has been relatively high and stable (Fagerberg, 1994; Grossman and Helpman, 1991)

Little focus on impact of R&D expenditure on growth performance of Newly Industrialized Economies (NIEs)

An extension of Wong, Ho and Toh (2009), our paper provides updated empirical estimates of the impact of R&D on economic performance in Singapore from 1978 to 2012.
METHODOLOGY

**Variables**
- **R&D** measured using national R&D expenditure
- **TFP** total factor productivity measures economic performance

**Method**
- **2 Step TFP Approach:** (Terlecky, 1974)
  1. Derive TFP from underlying production function
  2. Estimate equation relating R&D to TFP

**Production Function**
- **Cobb-Douglas Production Function**
  \[ Y = AK^\alpha L^\beta \]

  \( Y = output; A = BS^\gamma Z^\phi \) = productivity; \( \log A = TFP \)
  where S is stock of knowledge capital and Z represents other factors that affect productivity; K = stock of physical capital; L = labor employed.

THE IMPACT OF R&D ON THE SINGAPORE ECONOMY
FRAMEWORK FOR TFP

Assume Constant Returns to Scale ($\alpha+\beta=1$) and perfect competition in markets for labour and capital

In Log form: \[ TFP = \log B + \gamma \log S + \phi \log Z \]

Where
Log $B =$ constant, $S =$ stock of knowledge capital (R&D capital stock), $Z =$ other factors that affect productivity (e.g. education)

Note: $Z$ not considered in this analysis

SHORT-TERM ERROR CORRECTION MODEL (ECM)

If TFP and $\log S$ are cointegrated, assuming a ADL($x,y$) form, the short-run relationship is

\[ TFP_t = \beta + \lambda_1 TFP_{t-1} + \ldots + \lambda_x TFP_{t-x} + \gamma \log S_t + \ldots + \gamma_y \log S_{t-y} \]

Where: $\gamma$ (the coefficient on $\log S_t$) is the short-term elasticity of TFP with respect to knowledge stock
OTHER COMPUTED INDICATORS FROM ECM

1. Mean Lag
- Speed of adjustment in output growth to increases in R&D capital stock
  
  Mean lag = \( \sum \gamma_i / \sum \gamma_i \); or Mean lag = \( \lambda / (1-\lambda) \)

2. Median Lag
- Duration of the time lapse to observe half the total lag effect of R&D on output
  
  Median Lag = \( \log(0.5)/\log(\lambda) \)

3. Long Run Elasticity = \( \gamma / (1-\lambda) \)

4. Internal Rate of Return (IRR)
- Interest rate that makes the net present value of R&D investments equal to zero.
  
  High IRR → Higher profitability of investment
Applying the perpetual inventory method (Mohnen et al., 1986; Coe and Helpman, 1995), R&D capital stock in time $t$ is:

$$S_t = (1 - \delta) S_{t-1} + R_{t-1}$$

$$S_0 = \frac{R_0}{(g + \delta)}$$

**Critical factor:** Determining initial capital stock, when $t=0$ (Griliches, 1980)

Where

- $S_t (S_0) =$ Stock of R&D capital at time $t$ (at the beginning of the first year for which R&D expenditure data is available) (in constant prices)
- $R_t (R_0) =$ Expenditure on R&D during period (during the first year for which it is available) (in constant prices)
- $g =$ Average annual logarithmic growth of R&D expenditure over the period for which published R&D data were available
- $\delta =$ Depreciation rate of knowledge (assumed to be 10%)
## SINGAPORE DATA (1978-2012)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFP</td>
<td>Computed</td>
<td>TFP = ( \log Y - \alpha \log K - \beta \log L )</td>
</tr>
<tr>
<td>R&amp;D Capital Stock (S)</td>
<td>Computed</td>
<td>Computed using perpetual inventory method, with R&amp;D Expenditure data, assuming 10% depreciation</td>
</tr>
<tr>
<td>GDP (Y)</td>
<td>Singapore Department of Statistics (DOS)</td>
<td>In real terms based on year 2000 prices</td>
</tr>
<tr>
<td>Labour input (L)</td>
<td>Ministry of Manpower (MOM) Labour Force Survey</td>
<td></td>
</tr>
<tr>
<td>Stock of physical capital (K)</td>
<td>Computed</td>
<td>Computed using perpetual inventory method, with annual data on gross fixed capital formation (from DOS), assuming 5% depreciation</td>
</tr>
<tr>
<td>R&amp;D Expenditure</td>
<td>A*STAR Annual National R&amp;D Survey</td>
<td></td>
</tr>
</tbody>
</table>
R&D EXPENDITURE IN SINGAPORE
1978-2012

Total R&D Expenditure, SGD Million (Year 2000 prices)

Total R&D expenditure as share of GDP (%)

THE IMPACT OF R&D ON THE SINGAPORE ECONOMY
R&D CAPITAL STOCK AND TFP TREND, 1978-2012

THE IMPACT OF R&D ON THE SINGAPORE ECONOMY
CORRELATION BETWEEN R&D CAPITAL STOCK AND TFP, 1978-2012

\[ y = -1 \times 10^{-27}x^6 + 4 \times 10^{-22}x^5 - 3 \times 10^{-17}x^4 + 1 \times 10^{-12}x^3 - 2 \times 10^{-08}x^2 + 0.0001x + 1.2699 \]

\[ R^2 = 0.9246 \]
TESTING CO-INTEGRATION OF TIME SERIES DATA

1. Determine stationarity of variables

Augmented Dickey Fuller (ADF) Test on TFP and Log (S)

H₀: existence of unit root (time series data are non-stationary)

<table>
<thead>
<tr>
<th>Variable</th>
<th>ADF t-statistic (with intercept)</th>
<th>Prob</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFP</td>
<td>-0.92</td>
<td>0.77</td>
<td>Cannot reject null hypothesis of Non-stationarity</td>
</tr>
<tr>
<td>Log (S)</td>
<td>-0.71</td>
<td>0.96</td>
<td>Cannot reject null hypothesis of Non-stationarity</td>
</tr>
</tbody>
</table>

2. Given non-stationary nature of variables, determine if TFP and Log (S) are co-integrated? i.e. is there a long-run equilibrium relationship?

Estimate \( \text{TFP} = \log B + \gamma \log S \)

And test residuals to determine if this is a co-integrated relationship
LONG RUN RELATIONSHIP BETWEEN R&D AND TFP

Equation: TFP = log B + γ log S  
Method: Least Squares

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.79* (0.056)</td>
</tr>
<tr>
<td>Log (S) (R&amp;D Capital Stock)</td>
<td>0.090* (0.0066)</td>
</tr>
</tbody>
</table>

Adjusted R²: 0.85  
F-value: 190.02  
N: 1978 - 2012

Cointegration Test: ADF Test for unit root in residuals

<table>
<thead>
<tr>
<th>Series</th>
<th>ADF t-statistic</th>
<th>Prob</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residuals from TFP = log B + γlogS</td>
<td>-3.86</td>
<td>0.0071</td>
<td>Stationary (Cointegrated)</td>
</tr>
</tbody>
</table>

*Significant at 1% level  
Standard Errors in brackets

Conclusion: Residuals are stationary, TFP and Log (S) are co-integrated i.e. there exists a long-run equilibrium relationship between R&D capital stock and TFP
SHORT RUN ERROR CORRECTION MODEL (ECM)

Estimate equation in the general form:

\[ TFP_t = \beta + \lambda_1 TFP_{t-1} + \ldots + \lambda_x TFP_{t-x} + \gamma_t \log S_t + \ldots + \gamma_{t-x} \log S_{t-x} \]

Result after testing down to ADL(1,0):

\[ TFP_t = 0.22 + 0.73 TFP_{t-1} + 0.025 \log S_t \]

Computed Indicators from ECM:

<table>
<thead>
<tr>
<th>Impact of R&amp;D Capital in Singapore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Run Elasticity of TFP wrt R&amp;D</td>
</tr>
<tr>
<td>Short Run Elasticity of TFP wrt R&amp;D</td>
</tr>
<tr>
<td>Mean Lag, in years</td>
</tr>
<tr>
<td>Median Lag, in years</td>
</tr>
<tr>
<td>IRR (10 years)</td>
</tr>
<tr>
<td>IRR (5 years)</td>
</tr>
</tbody>
</table>

R&D investment is profitable especially in the long run (compared to market rates of 5-6% for bank loans)
### COMPARISON OF PARAMETER ESTIMATES FOR SINGAPORE & OTHER COUNTRIES

<table>
<thead>
<tr>
<th></th>
<th>Singapore</th>
<th>Singapore</th>
<th>Greece</th>
<th>16 OECD Countries</th>
<th>53 countries</th>
<th>22 OECD countries + Israel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable</td>
<td>TFP (based on GDP)</td>
<td>TFP (based on GDP)</td>
<td>TFP (based on GDP)</td>
<td>Private Sector TFP</td>
<td>Real GDP per capita</td>
<td>Private Sector TFP</td>
</tr>
<tr>
<td>Data Structure</td>
<td>Time series, single economy</td>
<td>Time series, single economy</td>
<td>Time series, single economy</td>
<td>Panel data of time series in multiple economies</td>
<td>Panel data of time series in multiple economies</td>
<td>Panel data of time series in multiple economies</td>
</tr>
<tr>
<td>Measure of R&amp;D</td>
<td>R&amp;D stock</td>
<td>R&amp;D stock</td>
<td>R&amp;D stock</td>
<td>R&amp;D stock</td>
<td>R&amp;D expenditure</td>
<td>R&amp;D stock</td>
</tr>
</tbody>
</table>

### PARAMETERS

<table>
<thead>
<tr>
<th></th>
<th>Singapore</th>
<th>Singapore</th>
<th>Greece</th>
<th>16 OECD Countries</th>
<th>53 countries</th>
<th>22 OECD countries + Israel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambda $\lambda$</td>
<td>0.728</td>
<td>0.837</td>
<td>0.039</td>
<td>0.82</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mean Lag</td>
<td>2.68</td>
<td>5.12</td>
<td>NA</td>
<td>4.55</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Median Lag</td>
<td>2.19</td>
<td>3.89</td>
<td>NA</td>
<td>3.49</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

‘Cycle time’ to create economic impact has improved in recent years in Singapore.

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**THE IMPACT OF R&D ON THE SINGAPORE ECONOMY**

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### COMPARISON OF PARAMETER ESTIMATES FOR SINGAPORE & OTHER COUNTRIES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Singapore (current paper)</th>
<th>Singapore (Ho et al, 2009)</th>
<th>Greece (Voutsinas &amp; Tsamadias, 2014)</th>
<th>16 OECD Countries (Guellec &amp; van Pottelsberghe de la Potterie, 2001)</th>
<th>53 countries</th>
<th>22 OECD countries + Israel (Coe and Helpman, 1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Term Elasticity with respect to R&amp;D</td>
<td>0.025</td>
<td>0.013</td>
<td>Non-significant</td>
<td>0.024 (private R&amp;D)</td>
<td>0.028 (public R&amp;D)</td>
<td>NA</td>
</tr>
<tr>
<td>Long Run Elasticity with respect to R&amp;D</td>
<td>0.091</td>
<td>0.081</td>
<td>0.038 (total R&amp;D)</td>
<td>0.13 (private R&amp;D)</td>
<td>0.075 (public R&amp;D)</td>
<td>0.17 (public R&amp;D)</td>
</tr>
</tbody>
</table>

- R&D capital in Singapore appears to be **less productive** than in OECD countries, in terms of responsiveness of output to research capital in the long run.

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**THE IMPACT OF R&D ON THE SINGAPORE ECONOMY**
COMPARISON OF PARAMETER ESTIMATES FOR SINGAPORE & OTHER COUNTRIES

Long run R&D productivity gap between Singapore and other countries may be attributed to:

1. **Nature of R&D activities in Singapore**
   - More downstream or focused in fields with shorter term economic impact (evidenced by Singapore’s shorter mean and median lag values)
   - Investments in emerging areas (e.g. life sciences) intensified only in the 2000s

2. **‘Leakage’ of Value Capture** ([Porter, 1990; Lepak, Smith & Taylor, 2007](#))
   - Unable to fully capture value created due to the lack of domestic demand and market conditions in Singapore
   - Presence of foreign firms which have avenues for repatriating income to their home countries or other markets

3. **Relatively Lower level of Private sector R&D activities in Singapore**
   - In 2011, government and higher education sectors’ share in total R&D expenditure was 38% in Singapore (OECD countries ≈ 30%)
COMPARATIVE ANALYSIS 1:

Testing for Structural Breaks

Aim:
To determine if there has been a significant shift in the short-run elasticity of TFP w.r.t R&D, as a result of a change in policy stances.

Chow Breakpoint Test for structural breaks:

Presence of structural breaks will imply that policy changes have induced changes in R&D productivity.

Periods in which there were notable new policies and institutional changes in Singapore's Science & Technology fields.
CHOW TEST FOR STRUCTURAL BREAKS

Apply Chow Test to ADL (1,0) ECM

\[ TFP_t = \beta + \lambda_1 TFP_{t-1} + \gamma_t \log S_t \]

<table>
<thead>
<tr>
<th>Break Point</th>
<th>F-statistic</th>
<th>Prob</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 (ASTAR, BMRC, SERC established)</td>
<td>0.65</td>
<td>0.59</td>
<td>No break</td>
</tr>
<tr>
<td>1995 (2\textsuperscript{nd} NSTP launched)</td>
<td>1.19</td>
<td>0.33</td>
<td>No break</td>
</tr>
<tr>
<td>1990 (NSTB established, 1\textsuperscript{st} NSTP launched)</td>
<td>0.27</td>
<td>0.85</td>
<td>No break</td>
</tr>
</tbody>
</table>

- Short-run elasticity of TFP w.r.t R&D has not changed significantly over the years.
- Institutional changes and introduction of national S&T plans are not associated with improved productivity of R&D in the short run
COMPARATIVE ANALYSIS 2: Causality between Public and Private R&D

Economics literature has studied extensively on the “social returns” generated by public R&D.

Impact of public sector R&D
✓ Direct effects on productivity
✓ Generates externalities and spillovers; stimulates private sector R&D

Aim:
To determine if there is causality between public and private R&D spending in Singapore.

Hypothesis:
Significant unidirectional causality from Public sector R&D to Private sector R&D

Private sector R&D outcomes depends on
a) Private sector efforts
b) Pool of knowledge that is accessible to the private sector (i.e., the outcomes of public R&D)
CAUSALITY BETWEEN PUBLIC AND PRIVATE R&D

Run Granger Causality Tests for causality in both directions 
($H_0: \sigma_1, \ldots, \sigma_x = 0$)

(1) Public R&D causes Private R&D
$$\log \text{Pte}_S_t = \alpha + \phi_1 \log \text{Pte}_S_{t-1} + \ldots + \phi_x \log \text{Pte}_S_{t-x} + \sigma_1 \log \text{Pub}_S_{t-1} + \ldots + \sigma_x \log \text{Pub}_S_{t-x}$$

(2) Private R&D causes Public R&D
$$\log \text{Pub}_S_t = \alpha + \phi_1 \log \text{Pub}_S_{t-1} + \ldots + \phi_x \log \text{Pub}_S_{t-x} + \sigma_1 \log \text{Pte}_S_{t-1} + \ldots + \sigma_x \log \text{Pte}_S_{t-x}$$
### Granger Causality Tests ($H_0: \sigma_1, \ldots, \sigma_x = 0$)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Sig</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Dependent = Private R&amp;D capital stock at time t</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log $Pte_{St} = \alpha + \phi_1 \log Pte_{St-1} + \ldots + \phi_x \log Pte_{St-x} + \delta_1 \log Pub_{St-1} + \ldots + \delta_x \log Pub_{St-x}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.141*</td>
<td>0.067</td>
</tr>
<tr>
<td>Private R&amp;D at t-1</td>
<td>1.295***</td>
<td>0.000</td>
</tr>
<tr>
<td>Private R&amp;D at t-2</td>
<td>-0.399***</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Public R&amp;D at t-1</strong></td>
<td>0.270**</td>
<td>0.029</td>
</tr>
<tr>
<td>Public R&amp;D at t-2</td>
<td>-0.170</td>
<td>0.1907</td>
</tr>
</tbody>
</table>

**Public R&D causes Private R&D**

**2) Dependent = Public R&D capital stock at time t**

Log $Pub_{St} = \alpha + \phi_1 \log Pub_{St-1} + \ldots + \phi_x \log Pub_{St-x} + \delta_1 \log Pte_{St-1} + \ldots + \delta_x \log Pte_{St-x}$

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Sig</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.133**</td>
<td>0.028</td>
</tr>
<tr>
<td>Public R&amp;D at t-1</td>
<td>1.766***</td>
<td>0.000</td>
</tr>
<tr>
<td>Public R&amp;D at t-2</td>
<td>-0.809***</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Private R&amp;D at t-1</strong></td>
<td>-0.123</td>
<td>0.337</td>
</tr>
<tr>
<td>Private R&amp;D at t-2</td>
<td>0.154</td>
<td>0.157</td>
</tr>
</tbody>
</table>

**Private R&D does not cause Public R&D**

Note: Results reported for VAR(2) structure. Findings were consistent when different lag structures were used.
KEY FINDINGS

1. Economic impact of R&D in the long term (elasticity= 0.091) is **almost four times** as much as the short run impact (elasticity = 0.025).

**Short run:**
- R&D productivity in Singapore is **comparable** to that of smaller advanced economies in the OECD.

**Long run:**
- Singapore’s R&D productivity **lags behind** the small OECD countries (Singapore LR elasticity= 0.091, OECD= 0.13-0.17)
- Compared to G7 nations, R&D productivity gap is even more considerable. ( G7 LR elasticity= 0.234)

   may be due to

   a) Nature of R&D activities in Singapore vs. OECD countries
   b) “Leakage” of value capture
KEY FINDINGS

**Comparative Analysis 1:**
- Impact of R&D in Singapore has not changed significantly in the last 30 years – no evidence of a structural break that induced higher short-term productivity of R&D

**Comparative Analysis 2:**
- Causality analysis shows that public R&D appear to generate positive externalities which in turn, stimulates R&D activity in the private sector and augments private R&D capital stock in Singapore
POLICY IMPLICATIONS FOR INCREASING ECONOMIC IMPACT OF R&D INVESTMENT

1. Policies to facilitate a greater degree of technology transfer from public to private sector
   - **Micro-targeted:** Financial grants for companies to license-in technologies from PRIs & universities; incentives for spin-off formation
   - **Macro-Level:** Vibrant entrepreneurship ecosystem with ready venture financing and incubation support; infrastructure for translational research

2. Initiatives to improve absorptive capacity of indigenous firms
   - Refine and extend existing programs to emphasize absorptive capacity in the form of expertise to integrate externally-sourced R&D into innovative products and services
   - Eg. T-UP program in Singapore has improved technology learning and enterprise innovation
3. Policies to retain value created by R&D investments within Singapore

- Increase localization of value capture activities of foreign firms
- Position Singapore as base for MNCs to locate their IP portfolio management activities for servicing the region (e.g. Patent Box)
THANK YOU
REFERENCES


THE IMPACT OF R&D ON THE SINGAPORE ECONOMY
BACK-UP SLIDES
SHORT RUN ERROR CORRECTION MODEL

Equation: $\text{TFP}_t = \beta + \lambda \text{TFP}_{t-1} + \gamma \log S_t$

Method: Least Squares

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.22*</td>
<td>(0.098)</td>
</tr>
<tr>
<td>$\text{TFP}_{t-1}$</td>
<td>0.73**</td>
<td>(0.12)</td>
</tr>
<tr>
<td>Log $S_t$ (R&amp;D Capital Stock)</td>
<td>0.025*</td>
<td>(0.018)</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>F-value</td>
<td>190.02</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1979 2012</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5 % level          ** Significant at 1% level
Standard Error in brackets

THE IMPACT OF R&D ON THE SINGAPORE ECONOMY
Lichtenberg (1992) suggested that marginal product of government-funded R&D capital is **lower** than private sector R&D capital; countries with higher government share in R&D spending exhibited lower productivity growth.

**Public sector share in Singapore R&D spending**

- Public sector (PRIs, government, IHLs) share in Singapore’s R&D expenditure averaged at **36%** in the last 10 years > Overall OECD average of **30%**.
ANNEX

Impact of Public vs. Private Sector R&D on TFP

Long Run TFP equation: (Guillec and van Pottelsberghe de la Potterie, 2001)

TFP = log B + \gamma_{pte} \log Pte_S + \gamma_{pub} \log Pub_S

Where:
Pte_S = Private R&D capital stock
Pub_S = Public R&D capital stock (PRIs, IHLs and government)

Computed using perpetual inventory method, with private and public R&D expenditure data from the A-STAR Annual Survey of R&D (\delta= 10%)

ADF unit root tests on log (Pte_S) and log (Pub_S) found that

- Log (Pte_S) is non-stationary
- Log (Pub_S) is found to be stationary.

Violates requirement of non-stationary variables in the long-run equation

Results of co-integration testing in the TFP equation needs to be interpreted with caution
LONG RUN RELATIONSHIP WITH TFP

Estimate:  \[ TFP = \log B + \gamma_{pte} \log Pte_S + \gamma_{pub} \log Pub_S \]

And test residuals to determine if TFP, \( \log (Pte_S) \) and \( \log (Pub_S) \) are co-integrated

Results:
- Residuals are weakly stationary (H₀ rejected only in ADF test without intercepts)
- Tentatively suggest co-integration i.e. there exists a long run equilibrium relationship between TFP and public & private R&D capital stock

Short Run ECM

ECM representation in the general form:

\[ TFP_t = \beta + \lambda_1 TFP_{t-1} + \ldots + \lambda_x TFP_{t-x} + \gamma_{pte,t} \log Pte_{S,t} + \ldots + \gamma_{pte,t-x} \log Pte_{S,t-x} + \gamma_{pub,t} \log Pub_{S,t} + \ldots + \gamma_{pub,t-x} \log Pub_{S,t-x} \]

Tested down to ADL (1,1)

THE IMPACT OF R&D ON THE SINGAPORE ECONOMY
PRIVATE AND PUBLIC R&D: COMPUTED INDICATORS FROM ECM

<table>
<thead>
<tr>
<th></th>
<th>Total R&amp;D Capital Stock</th>
<th>Private R&amp;D capital stock</th>
<th>Public R&amp;D capital stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Run Elasticity of TFP w.r.t R&amp;D</td>
<td>0.091</td>
<td>0.055</td>
<td>0.035</td>
</tr>
<tr>
<td>Short Run Elasticity of TFP w.r.t R&amp;D</td>
<td>0.025</td>
<td>0.016</td>
<td>0.010</td>
</tr>
<tr>
<td>Mean Lag, in years</td>
<td>2.68</td>
<td>1.27</td>
<td>2.69</td>
</tr>
<tr>
<td>Median Lag, in years</td>
<td>2.19</td>
<td>1.24</td>
<td>3.21</td>
</tr>
<tr>
<td>Internal Rate of Return 10 years</td>
<td>20.8%</td>
<td>21.1%</td>
<td>23.8%</td>
</tr>
<tr>
<td>Internal Rate of Return 5 years</td>
<td>6.8%</td>
<td>5.9%</td>
<td>12.5%</td>
</tr>
</tbody>
</table>

For both Private & Public R&D capital stock:
- Long run elasticity of TFP w.r.t R&D is approximately 3.5xs of short run elasticity

Comparing Public & Private sectors:
- Private R&D has higher TFP/R&D elasticity more productive than public R&D
- Private R&D has more immediate impact on TFP
- **But** Public R&D has higher IRR in both the 5-year & 10-year period