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THE IMPACT OF R&D ON THE SINGAPORE ECONOMY:

A TIME SERIES ANALYSIS

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OVERVIEW

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- Current empirical literature on R&D's contribution to economic growth largely focuses on:
  a) Research at the firm or industry level (Australian Industry Commission, 1995; Link and Siegel, 2003)
  b) 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

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Variables

R&D measured using national R&D expenditure

TFP total factor productivity measures economic performance

Method

2 Step TFP Approach: (Terleckjy, 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.

FRAMEWORK FOR TFP

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

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

TFP: the increase in output not explained by changes in capital and labour – "Solow residual"

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

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

Where: γ (the coefficient on **log** $\mathbf{S_t}$) 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

$$\text{Mean lag} = \Sigma\, i\gamma_i / \Sigma\gamma_i \text{ ; or } \text{Mean lag} = \lambda/(1-\lambda)$$

2. Median Lag

- Duration of the time lapse to observe half the total lag effect of R&D on output

$$\text{Median Lag} = \log(0.5)/\log(\lambda)$$

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

CONSTRUCTING R&D CAPITAL STOCK DATA

Applying the perpetual inventory method (Mohnen et al., 1986; Coe and Helpman, 1995),

R&D capital stock in time t is:

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

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

$$S_o = R_o/(g + \delta)$$

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

δ = Depreciation rate of knowledge (assumed to be 10%)

SINGAPORE DATA (1978-2012)

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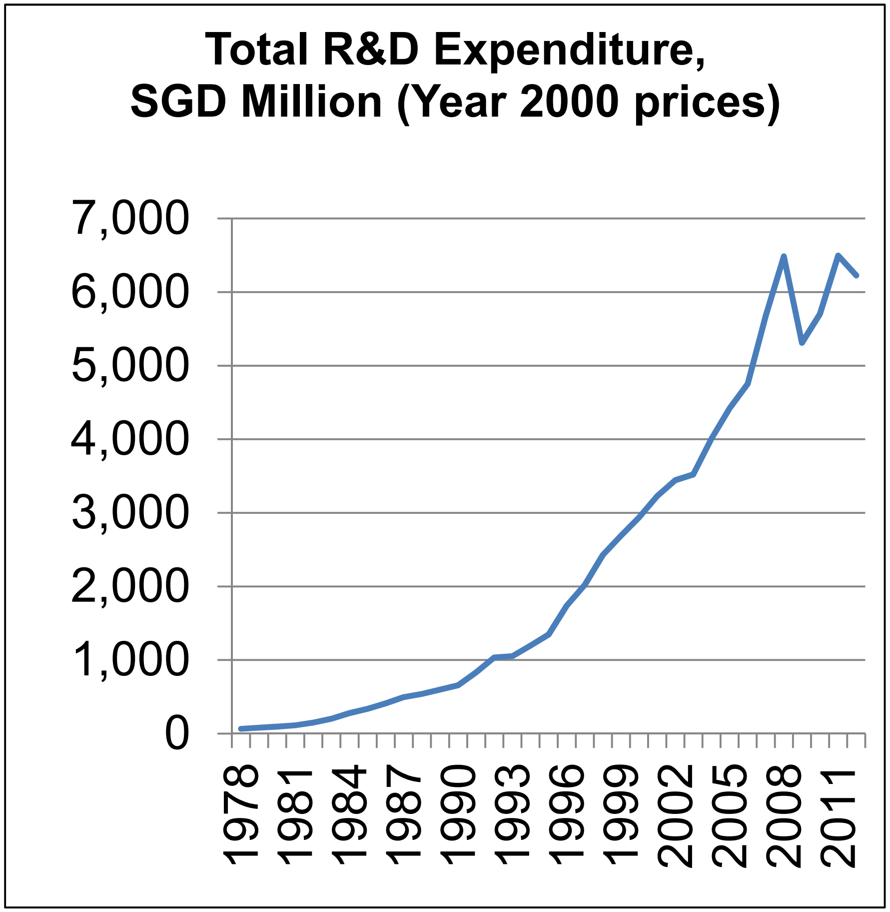
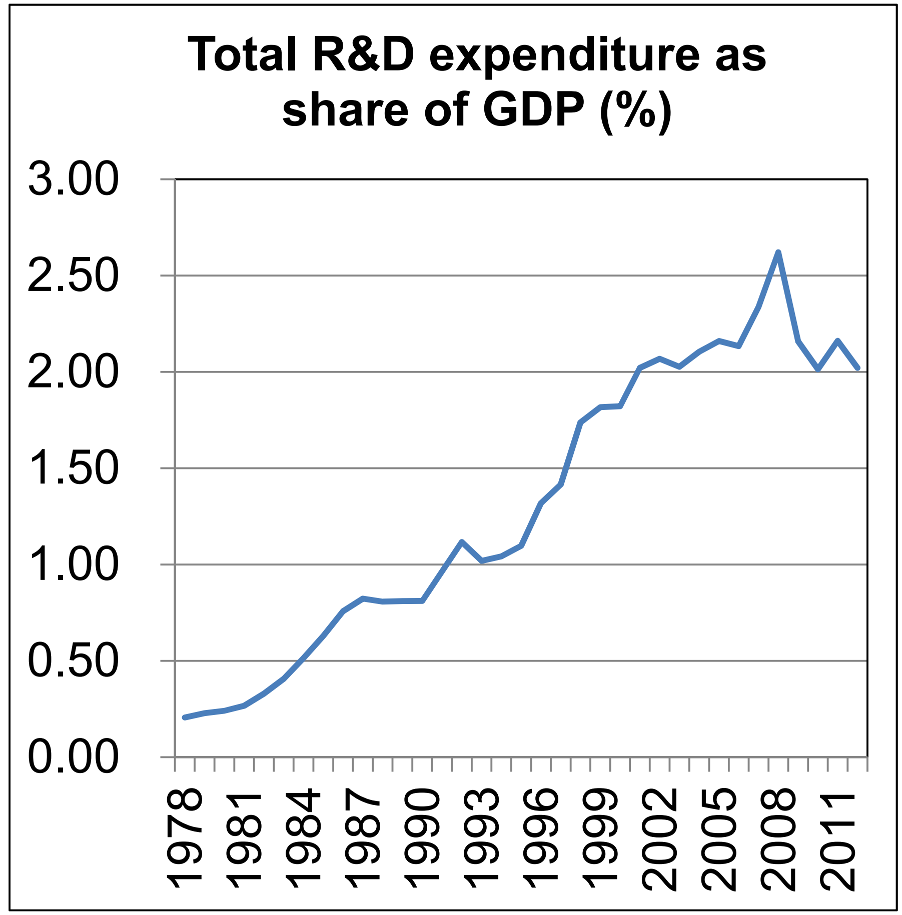
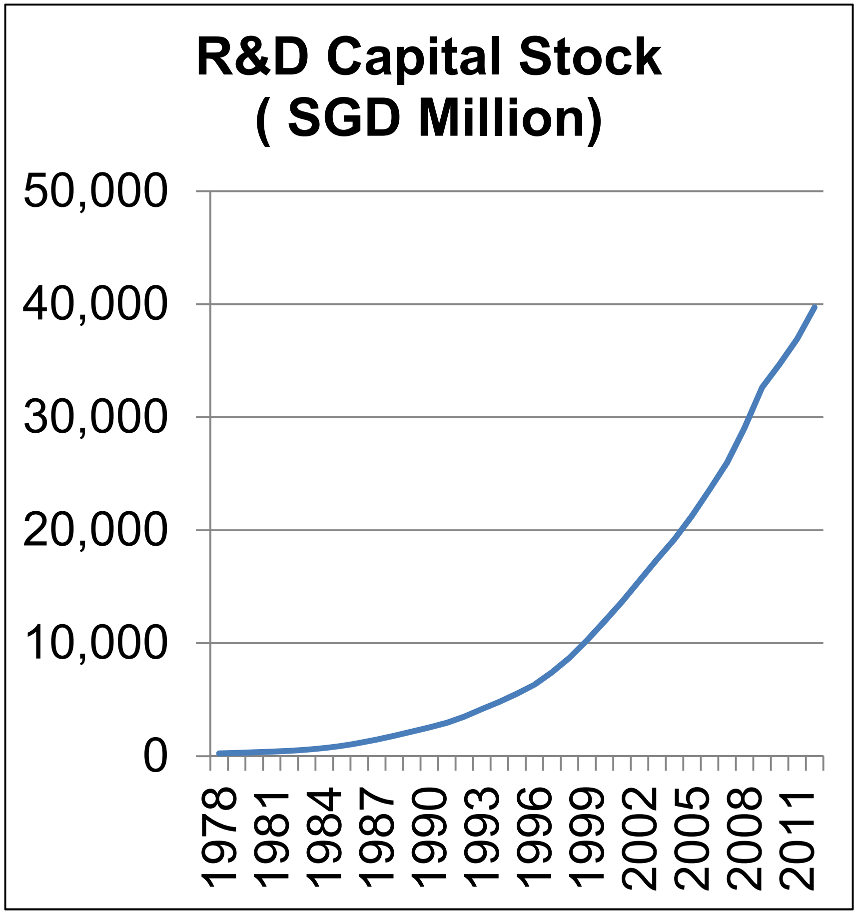
Variable	Source	Remarks
TFP	Computed	TFP = log Y - αlogK - βlogL
R&D Capital Stock (S)	Computed	Computed using perpetual inventory method, with R&D Expenditure data, assuming 10% depreciation
GDP (Y)	Singapore Department of Statistics (DOS)	In real terms based on year 2000 prices
Labour input (L)	Ministry of Manpower (MOM) Labour Force Survey	
Stock of physical capital (K)	Computed	Computed using perpetual inventory method, with annual data on gross fixed capital formation (from DOS), assuming 5% depreciation
R&D Expenditure	A*STAR Annual National R&D Survey	

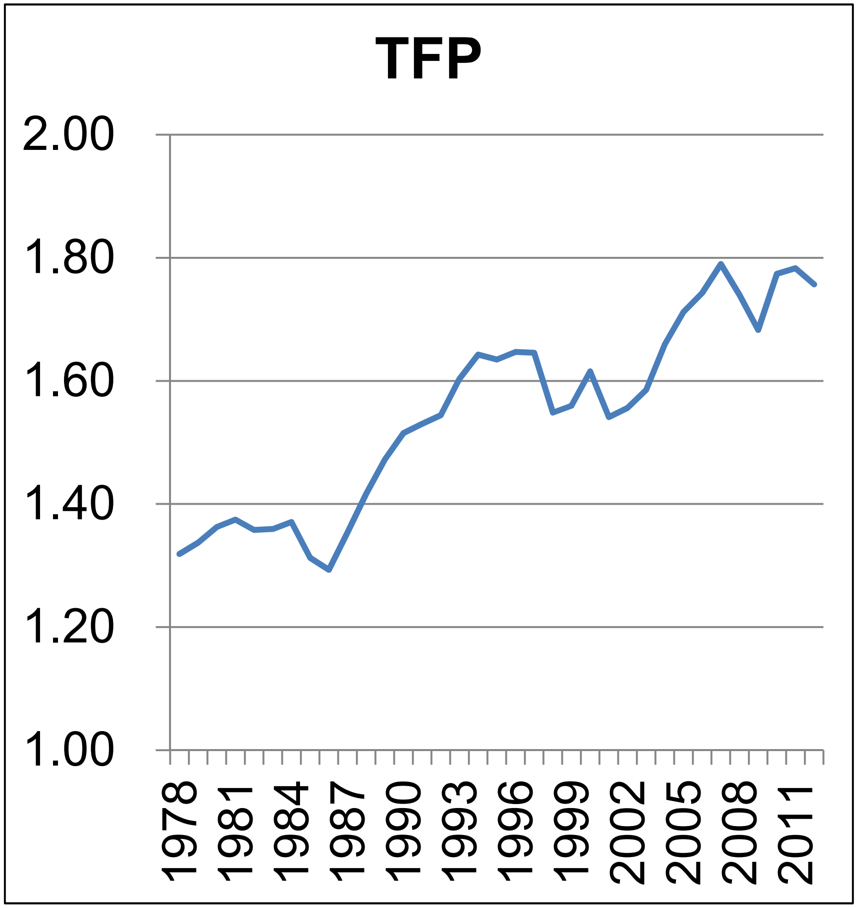
R&D EXPENDITURE IN SINGAPORE 1978-2012



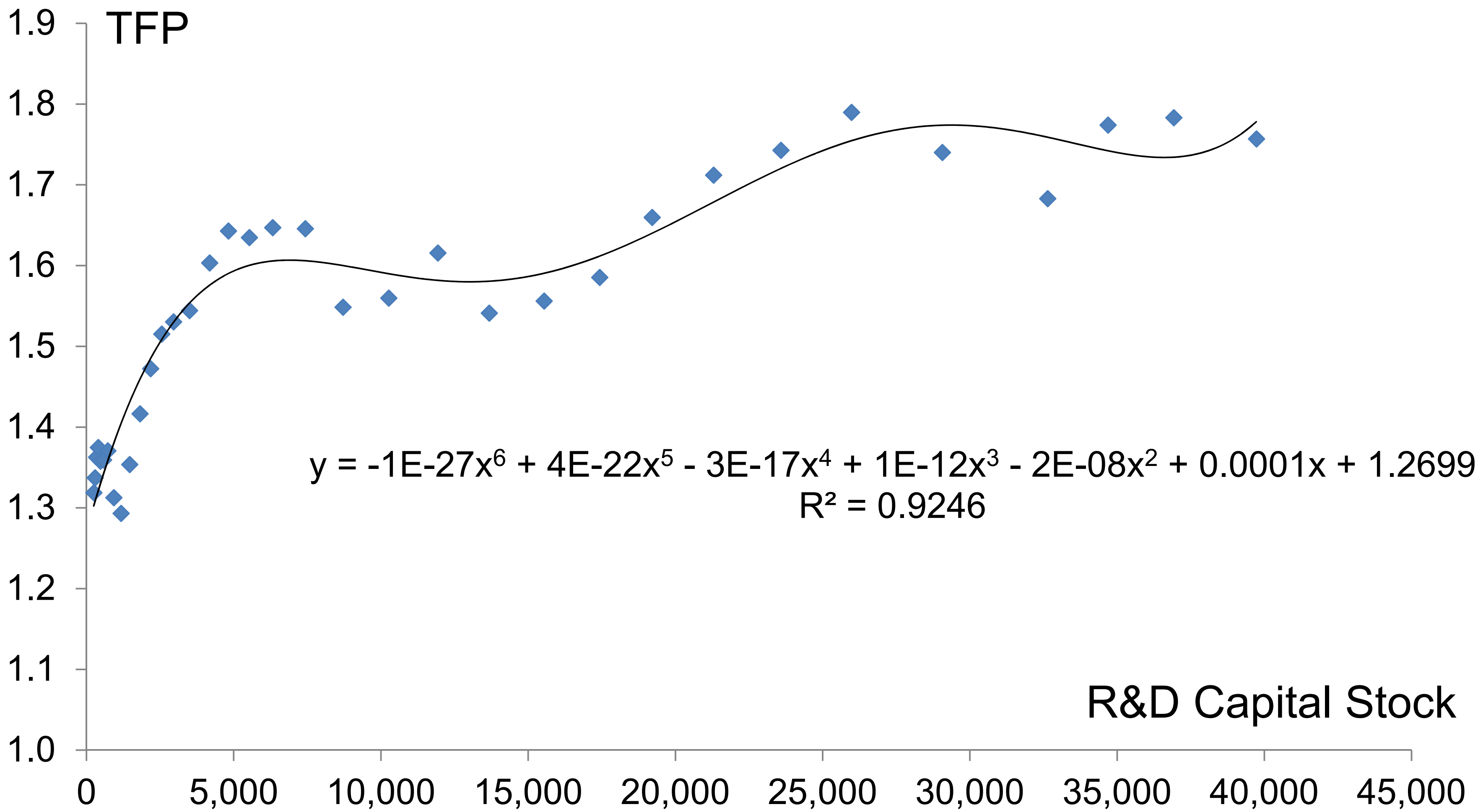


R&D CAPITAL STOCK AND TFP TREND, 1978-2012





CORRELATION BETWEEN R&D CAPITAL STOCK AND TFP, 1978-2012



TESTING CO-INTEGRATION OF TIME SERIES DATA

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1. Determine stationarity of variables

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

H_0: existence of unit root (time series data are non-stationary)

Variable	ADF t-statistic (with intercept)	Prob	Conclusion
TFP	-0.92	0.77	Cannot reject null hypothesis of Non-stationarity
Log (S)	-0.71	0.96	Cannot reject null hypothesis of Non-stationarity

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 $TFP = \log B + \gamma \log S$

And test residuals to determine if this is a co-integrated relationship

LONG RUN RELATIONSHIP BETWEEN R&D AND TFP

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Equation: TFP = log B + γ log S **Method: Least Squares**	
Variable	**Coefficient**
C	0.79* (0.056)
Log (S) (R&D Capital Stock)	0.090* (0.0066)
Adjusted R^2	0.85
F-value	190.02
N	1978 2012

Cointegration Test: ADF Test for unit root in residuals			
Series	**ADF t-statistic**	**Prob**	**Conclusion**
Residuals from TFP = logB + γlogS	-3.86	0.0071	Stationary (Cointegrated)

*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):

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

Significant lagged effect in the contribution of R&D to TFP

Computed Indicators from ECM:

Impact of R&D Capital in Singapore	
Long Run Elasticity of TFP wrt R&D	0.091
Short Run Elasticity of TFP wrt R&D	0.025
Mean Lag, in years	2.68
Median Lag, in years	2.19
IRR (10 years)	20.8%
IRR (5 years)	6.8%

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

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	Singapore (Current paper)	Singapore (Ho et al, 2009)	Greece (Voutsinas & Tsamadias, 2014)	16 OECD Countries (Guellec & van Pottelsberghe de la Potterie, 2001)	53 countries (Lichtenberg, 1992)	22 OECD countries + Israel (Coe and Helpman, 1995)
Dependent Variable	**TFP (based on GDP)**	TFP (based on GDP)	TFP (based on GDP)	Private Sector TFP	Real GDP per capita	Private Sector TFP
Production Function	**Cobb-Douglas**	Cobb-Douglas	Cobb-Douglas	Cobb-Douglas	Cobb-Douglas	Cobb-Douglas
Data Structure	**Time series, single economy**	Time series, single economy	Time series, single economy	Panel data of time series in multiple economies	Panel data of time series in multiple economies	Panel data of time series in multiple economies
Measure of R&D	**R&D stock**	R&D stock	R&D stock	R&D stock	R&D expenditure	R&D stock
Period of Estimation	**1978-2012**	1978-2001	1987-2007	1980-1998	1985	1971-1990
PARAMETERS						
Lambda λ	0.728	0.837	0.039	0.82	NA	NA
Mean Lag	**2.68**	5.12	NA	4.55	NA	NA
Median Lag	**2.19**	3.89	NA	3.49	NA	NA

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

COMPARISON OF PARAMETER ESTIMATES FOR SINGAPORE & OTHER COUNTRIES

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	Singapore (current paper)	**Singapore** (Ho et al, 2009)	**Greece** (Voutsinas & Tsamadias, 2014)	**16 OECD Countries** (Guellec & van Pottelsberghe de la Potterie, 2001)	**53 countries** (Lichtenberg, 1992)	**22 OECD countries + Israel** (Coe and Helpman, 1995)
PARAMETERS CONTINUED						
Short Term Elasticity with respect to R&D	**0.025**	0.013	Non-significant	0.024 (private R&D) 0.028 (public R&D)	NA	NA
Long Run Elasticity with respect to R&D)	**0.091**	0.081	0.038 (total R&D) 0.075 (public R&D)	0.13 (private R&D) 0.17 (public R&D)	0.068 to 0.077	0.078 (non-G7) 0.234 (G7)

- 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.

COMPARISON OF PARAMETER ESTIMATES FOR SINGAPORE & OTHER COUNTRIES

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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

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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:

- ❑ In year 2000 (compare 1978-2000 vs 2001-2012)
- ❑ In year 1995 (compare 1978-1995 vs 1996-2012)
- ❑ In year 1990 (compare 1978-1990 vs 1991-2012)

Periods in which there were notable new policies and institutional changes in Singapore's Science & Technology fields.

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

CHOW TEST FOR STRUCTURAL BREAKS

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Apply Chow Test to ADL (1,0) ECM

$$TFP_t = \beta + \lambda_1 \, TFP_{t-1} + \gamma_t \log S_t$$

Break Point	F-statistic	Prob	Conclusion
2000 (ASTAR, BMRC, SERC established)	0.65	0.59	No break
1995 (2nd NSTP launched)	1.19	0.33	No break
1990 (NSTB established, 1st NSTP launched)	0.27	0.85	No break

- **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

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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 →

Private sector R&D outcomes depends on
a) Private sector efforts
b) Pool of knowledge that is accessible to the private sector (ie. the outcomes of public 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

CAUSALITY BETWEEN PUBLIC AND PRIVATE R&D

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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

$$\log Pte\_S_t = \alpha + \phi_1 \log Pte\_S_{t-1} + \ldots + \phi_x \log Pte\_S_{t-x} + \sigma_1 \log Pub\_S_{t-1} + \ldots + \sigma_x \log Pub\_S_{t-x}$$

(2) Private R&D causes Public R&D

$$\log Pub\_S_t = \alpha + \phi_1 \log Pub\_S_{t-1} + \ldots + \phi_x \log Pub\_S_{t-x} + \sigma_1 \log Pte\_S_{t-1} + \ldots + \sigma_x \log Pte\_S_{t-x}$$

Granger Causality Tests (H_0: $\sigma_1,\dots,\sigma_x = 0$)

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	Coefficient	Sig	Conclusion
1) Dependent = Private R&D capital stock at time t			
$\text{Log Pte\_S}_t = \alpha + \phi_1 \text{ log Pte\_S}_{t-1} + \dots + \phi_x \text{ log Pte\_S}_{t-x} + \delta_1 \text{ log Pub\_S}_{t-1} + \dots + \delta_x \text{ log Pub\_S}_{t-x}$			
Constant	0.141*	0.067	
Private R&D at t-1	1.295***	0.000	**Public R&D causes Private R&D**
Private R&D at t-2	-0.399***	0.007	
Public R&D at t-1	**0.270****	0.029	
Public R&D at t-2	-0.170	0.1907	
2) Dependent = Public R&D capital stock at time t			
$\text{Log Pub\_S}_t = \alpha + \phi_1 \text{ log Pub\_S}_{t-1} + \dots + \phi_x \text{ log Pub\_S}_{t-x} + \delta_1 \text{ log Pte\_S}_{t-1} + \dots + \delta_x \text{ log Pte\_S}_{t-x}$			
Constant	0.133**	0.028	
Public R&D at t-1	1.766***	0.000	Private R&D does not cause Public R&D
Public R&D at t-2	-0.809***	0.000	
Private R&D at t-1	-0.123	0.337	
Private R&D at t-2	0.154	0.157	

Public sector R&D contributes to increased private sector R&D, with a one year lag between cause and effect

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

KEY FINDINGS

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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).

2

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

3

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

4

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

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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

POLICY IMPLICATIONS FOR INCREASING ECONOMIC IMPACT OF R&D INVESTMENT

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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

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BACK-UP SLIDES

SHORT RUN ERROR CORRECTION MODEL

Equation: $TFP_t = \beta + \lambda TFP_{t-1} + \gamma \log S_t$ Method: Least Squares	
Variable	**Coefficient**
C	0.22* (0.098)
TFP_{t-1}	0.73** (0.12)
Log S_t (R&D Capital Stock)	0.025* (0.018)
Adjusted R^2	0.85
F-value	190.02
N	1979 2012

*Significant at 5 % level

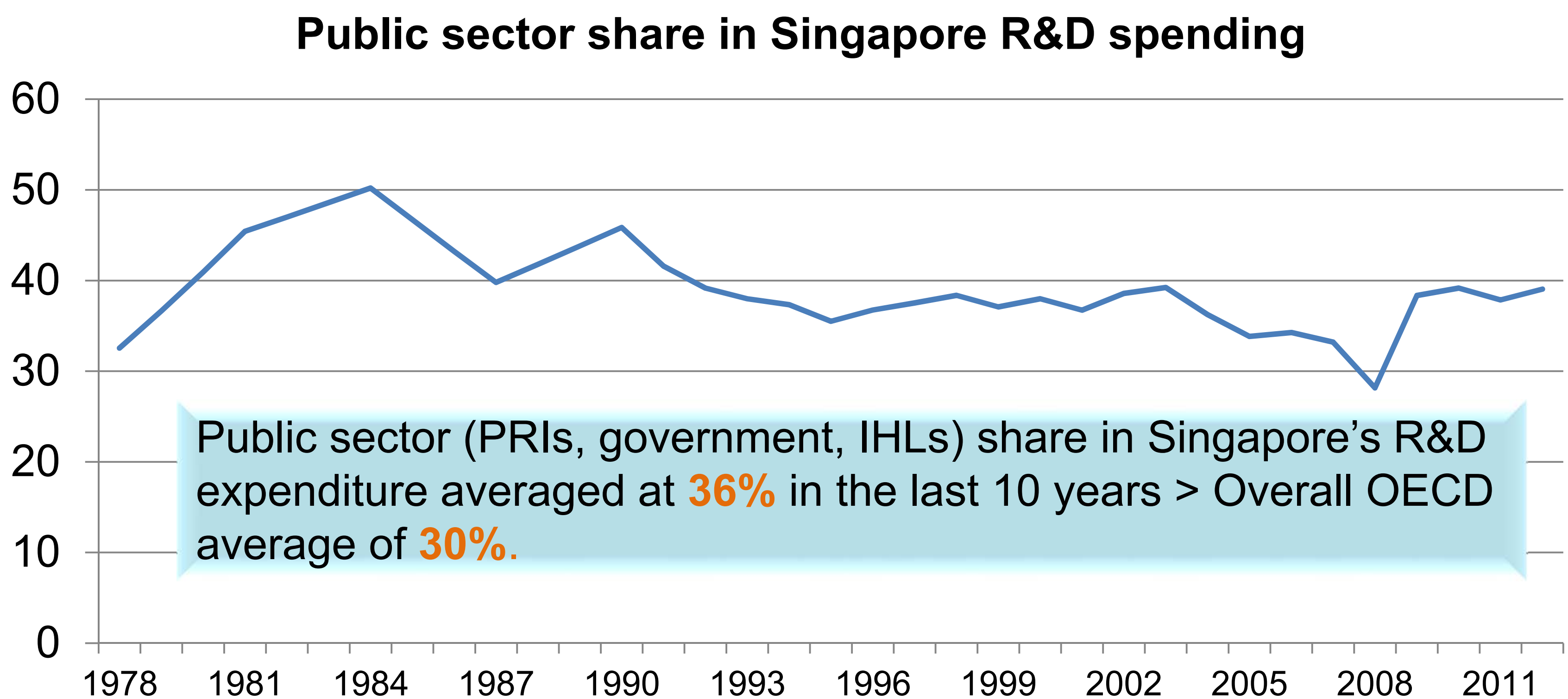
** Significant at 1% level

Standard Error in brackets

ANNEX

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

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.



ANNEX

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

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Long Run TFP equation: (Guellec 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 (δ= 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

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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 (H_0 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)

PRIVATE AND PUBLIC R&D: COMPUTED INDICATORS FROM ECM

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

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