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R&D spillovers, information technology and telecommunications, and productivity in ASIA and the OECD

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Abstract

This paper examines the role research and development (R&D) plays in technology progress for a sample of OECD and Asian economies from 1980 to 1995. An empirical model is estimated which relates total factor productivity to domestic and foreign R&D activity, trade, and information technology and telecommunications (ITT). Model estimates confirm a positive relationship between national productivity and R&D activity exists in the long run. Further, the benefits of R&D can spillover countries through trade, in particular, trade in ITT equipment. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Endogenous growth models emphasise innovation and trade as vehicles for technological spillovers that permit developing countries to catch up to industrialised countries. The creation and accumulation of knowledge can improve sectoral and national productivity through the invention of intermediate goods (or by improving the quality of existing goods), which bring about the more effective use of existing resources (Grossman and Helpman, 1991). The role knowledge

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plays in technological progress has been the subject of much recent attention in the economic growth literature. Several studies find that the returns from investment in knowledge are positive, and they are greater than returns from investment in equipment, infrastructure and machinery (Griliches, 1988, 1994; Nadiri, 1993; Coe and Helpman, 1995). Further, Coe and Helpman (1995) argue that own knowledge enhances a country's ability to take advantage of innovation and technological advance elsewhere.

Coe and Helpman (1995) extend Grossman and Helpman's (1991) 'product variety' model of innovation to show that national productivity increases with the accumulation of both domestic and foreign knowledge (see also Bayoumi et al., 1996). Employing annual cross-section, time-series data for 21 OECD economies and Israel from 1971 to 1990, Coe and Helpman (1995) demonstrate a significant positive relationship between total factor productivity (TFP) and knowledge, approximated by research and development (R&D) capital stock, exists. Further, the benefits of R&D can also spread to (spillover) other countries through trade when measured by the share of aggregate imports to gross domestic product (GDP). The predicted convergence occurs only when knowledge spills over perfectly between countries. This finding has important implications for national trade liberalisation and economic integration policy. For instance, Feenstra (1996) shows that when knowledge spills over imperfectly between countries, small open economies may experience slower rates of economic growth rates after trade liberalisation and integration.

Application of the above findings to particular national circumstances is somewhat problematic as received empirical evidence usually relate to OECD economies and aggregate imports are nominated as the sole channel for the transmission of R&D spillovers internationally. Coe et al. (1997) extend their sample to 77 developing economies, and estimate an equation that relates TFP to foreign R&D capital, imports of machinery and equipment relative to GDP, and educational attainment.[1] This TFP equation does not include an argument for domestic R&D for developing countries since these data are scarce. Model estimates indicate that a 1% increase in the foreign R&D stocks of industrialised countries (in the 'North') raises output of the developing countries (in the 'South') by 0.06%.[2] However, the assumption of negligible domestic R&D in developing countries is unacceptable for some 'high income' Asian countries contained in

[1] To ensure that trade benefits domestic productivity, trade partners must provide products and information in which the domestic country is in short supply. By trading with an industrial country that has a larger 'stock of knowledge' a developing country stands to gain more in terms of both the products it can import and the direct knowledge it can acquire than it would by trading with another developing country (Coe et al., 1997).

[2] Coe et al. (1997) consider how the interaction of education attainment with foreign R&D affects productivity, and find the secondary school enrolment ratio has no significant effect on the marginal benefit of foreign R&D. Engelbrecht (1997a) finds that human capital has a positive impact on productivity only when it interacts with a productivity catch up variable.

their sample. Madden and Savage (2000) address this potential source of error by estimating a model that relates TFP to both domestic and foreign R&D activity for a sample of OECD and Asian nations. They find that TFP growth in Chinese Taipei, India, Indonesia, Singapore, South Korea and Thailand is augmented by investment in own R&D.

Lichtenberg and Van Pottelsberghe de la Potterie (1996); Engelbrecht (1997a,b) and Madden and Savage (2000) suggest that Coe and Helpman (1995) and Coe et al. (1997) place too much emphasis on aggregate openness and education as channels for international knowledge transfer. For instance, Lichtenberg and Van Pottelsberghe de la Potterie (1996) and Engelbrecht (1997a) identify training received abroad, foreign direct investment, electronic information transfer, and imports of books and journals as potentially important transmission mechanisms for international R&D spillovers. Madden and Savage (2000) argue that information technology and telecommunications (ITT) is an important source of international knowledge transfer in an emerging global information economy. International trade in ITT equipment and services generates direct productivity benefits through lower transaction costs and improved marketing information, and indirect benefits due to accelerated information and knowledge diffusion across borders (Jussawalla and Lamberton, 1982; Antonelli, 1991). As such, ITT and trade policy are becoming a priority for many governments and international agencies endeavouring to improve national productivity and economic growth (European Bank for Reconstruction and Development 1995; OECD, 1996a; Spiller and Cardilli, 1997).

This study examines the role that R&D activity plays in technological progress for a sample of OECD and Asian economies for the period from 1980 through 1995 using annual data. So as to assess the importance of alternative potential sources of TFP growth a series of models are developed from the Coe and Helpman (1995) specification. A composite model relates TFP to domestic and foreign R&D activity, trade, and ITT. Model estimates are used to calculate the TFP elasticity with respect to OECD and Asian domestic R&D, respectively, and individual country foreign R&D elasticity's of TFP. The TFP equation and estimation method employed here differs from those of previous studies. First, the sample includes Asian measures of domestic R&D expenditures. Inclusion of Asian data allows further examination of the Coe et al. (1997) hypothesis that developing economies with low own R&D benefit from OECD R&D activity. Measures of ITT trade are also included in the TFP equation to allow alternative channels for the international transfer of R&D. Finally, the Im et al. (IPS 1997) group mean panel unit root test is used to establish the order of integration and cointegration of these panel data. The paper is organised as follows. Section 2 describes the econometric method used to estimate TFP elasticities. Data used in estimation are presented in Section 3. Section 4 reports estimation results, and elasticity calculations for TFP with respect to R&D. Section 5 presents conclusions.

2. Econometric method

Following Coe and Helpman (1995), the basic TFP equation used to assess the importance of R&D spillovers is:

$$\log \mathrm{TFP}_{it} = \alpha_{0i} + \alpha_1 \log \mathrm{DRD}_{it} + \alpha_2 \log \mathrm{FRD}_{it} + e_{it} \tag{1}$$

where $i=1, \ldots, n$ denotes countries and $t=1, \ldots, T$ the year, DRD is domestic R&D capital stock, FRD is foreign R&D capital (measured as country i's bilateral import share weighted-average of the domestic R&D capital stocks of its trading partners), the α's are unknown parameters to be estimated, and e is a white noise error term. The parameter vector α_{0i} captures country-specific effects on productivity not captured by DRD and FRD, whilst α_1 and α_2 are the elasticity's of TFP with respect to domestic and foreign R&D capital stocks, respectively.[3]

Eq. (1) can be modified to allow the TFP elasticity with respect to domestic R&D to vary between OECD and Asian economies, and to account for the interaction between foreign R&D and the level of international trade. When two countries have the same import composition, and their trading partners have the same composition of R&D capital stocks, the country that imports more relative to GDP would benefit more from foreign R&D. Openness to trade enables a country to embrace a wider variety of intermediate products and capital equipment, which enhances the productivity of its own resources. Trade also provides a channel to stimulate the learning of production methods, product design, organisational methods and market conditions from across borders (Grossman and Helpman, 1991; Coe et al., 1997). A modified TFP equation that incorporates these channels is:

$$\begin{aligned} \log \mathrm{TFP}_{it} = \beta_{0\mathrm{i}} &+ \beta_1 \log \mathrm{DRD}_{it} + \beta_2 \mathrm{ASIA} \log \mathrm{DRD}_{it} \\ &+ \beta_3 (M/Y)_{it} \log \mathrm{FRD}_{it} + u_{it} \end{aligned} \tag{2}$$

where ASIA equals one for Asian countries and zero otherwise, M/Y is the share of aggregate imports to GDP, the β's are unknown parameters to be estimated, and u is a white noise error term.[4] The interaction term ASIA log DRD allows the elasticity of TFP with respect to domestic R&D, $\beta_1 + \beta_2$ASIA, to vary between the Asian and OECD economies in the sample, whilst the term $\beta_3(M/Y)$ provides a measure of the elasticity of TFP with respect to foreign R&D.

Another channel of influence on domestic TFP considered are ITT sector imports. In particular, ITT equipment can give rise to substantial external economies through the use of more advanced technology embedded in the equipment, and the extra skills acquired by users of the equipment (Aschauer,

[3] Eq. (1) assumes log TFP, log DRD and log FRD are integrated $I(1)$. Under the null hypothesis of no cointegration the residuals are also $I(1)$.

[4] M/Y is assumed $I(1)$.

1989; Cronin et al., 1993; Greenstein and Spiller, 1995; Karunaratne, 1995; Madden and Savage, 1998).[5] Since ITT is generally considered to be a high-technology sector trade in ITT enhances the potential for the intended and tacit promotion of human capital development and research (Jussawalla and Lamberton, 1982; Greenstein and Spiller, 1995). These benefits can create substantial efficiencies in production that have the potential to flow through to all sectors of the economy. ITT service trade allows more effective communication, reduces the cost of acquiring information and expands the stock of available entrepreneurial talent. Increased information flows also assist in the integration of domestic and international markets and have potential to enhance national income and productivity through increased competition and market efficiency. Further, Antonelli (1991) suggests the diffusion of advanced ITT services provides a means by which developing countries can overcome information asymmetries and take advantage of opportunities for technology catch up. Accordingly, (2) is modified to account for the impact of ITT on productivity through foreign R&D:

$$\log \mathrm{TFP}_{it} = \delta_{0i} + \delta_1 \log \mathrm{DRD}_{it} + \delta_2 \mathrm{ASIA7} \log \mathrm{DRD}_{it} + \delta_3 (M/Y)_{it} \log \mathrm{FRD}_{it} + \delta_4 \mathrm{COM}_{it} \log \mathrm{FRD}_{it} + \delta_5 \mathrm{TEL}_{it} \log \mathrm{FRD}_{it} + v_{it} \tag{3}$$

where the potential impact of ITT on TFP occurs through COM (the share of communications and computer equipment in imports) and TEL (the outgoing international message telephone service (IMTS) minutes per person). The δs are unknown parameters to be estimated, and v is a white noise error term.[6]

The parameter vector δ_{0i} controls for mean country-specific productivity variations not due to DRD and FRD. There are no a priori expectations for the signs of the parameters contained in δ_{0i}. Grossman and Helpman (1991) show TFP increases with DRD capital so $\delta_1 > 0$ is expected. The parameter of ASIA log DRD parameter has no anticipated sign, that is, since R&D may be more or less effective in enhancing productivity. Coe and Helpman (1995) argue that industrial country TFP is more responsive to own R&D since larger economies perform R&D across a wider spectrum of R&D activities, and are more adept at exploiting complementarities. Finding $\delta_2 < 0$ would support Coe and Helpman's conjecture. By contrast, when domestic R&D is subject to diminishing returns, countries with high levels of domestic R&D gain less from increased in domestic R&D than countries with lower domestic R&D activity. Accordingly, $\delta_2 > 0$ suggests diminishing returns to R&D capital. Finally, δ_2, δ_3, $\delta_4 > 0$ indicate the impact of

[5] Economies are transmitted through human capital accumulation, improved efficiency and innovation, and the efficient exchange of information and knowledge (DeLong and Summers, 1991; Wolff, 1991).

[6] In foreign trade, outgoing IMTS calls are considered an import because the (domestic) originating carrier must reimburse the (foreign) terminating carrier for costs incurred in terminating the incoming call. The foreign R&D TFP elasticity is now $\delta_3(M/Y) + \delta_4 \mathrm{COM}_{it} + \delta_5 \mathrm{TEL}$. Both COM and TEL are assumed $I(1)$.

foreign R&D on domestic TFP is larger the more open an economy is to both aggregate trade and trade in ITT.

Estimation of R&D spillovers from the panel data models (1) through (3) requires that care be taken to understand the underlying time-series properties of these data. Not correctly identifying the order of integration and cointegration for TFP and R&D variables can lead to spurious inference. Coe and Helpman (1995), for example, use pooled residuals from a TFP equation and report a cointegrating relationship exists between TFP and R&D when applying the augmented Dickey-Fuller (ADF; 1981) test to their TFP equation residuals. However, TFP and R&D are not cointegrated under the pooled residual unit root test proposed by Levin and Lin (1993). Edmond (1998) attempts to avoid such ambiguity by applying the group mean panel unit root test proposed by IPS (1997) to the Coe and Helpman data set. By pooling the ADF statistics of all countries comprising the panel into an average ADF value across all countries, IPS show their test has more power than those for single time-series, and better finite sample properties than pooled residual unit root tests. Accordingly, Edmond finds that TFP and R&D are stationary in first-differences, and the TFP equation is cointegrated. IPS developed a panel unit root test based on the stochastic process, which can be observed many times. Mean country ADF statistics are more general and powerful in finite samples than the pooled residual tests of Engle and Granger (1987); Levin and Lin (1993) and Quah (1994). The IPS group mean panel unit root test allows countries within a panel to have different ADF statistics and lag structures. It is obtained from the ADF($\mathrm{p_i}$) auxiliary equation:

$$\Delta \ln Z_{it} = \mu_i + \gamma t + \phi_i \ln Z_{it-1} + \sum_{j=1}^{p_i} \rho_{ij} \Delta \ln Z_{it-j} + \epsilon_{it} \tag{4}$$

where Z is the variable under examination, Δ is the first-difference operator, t is a deterministic time trend, μ, γ, ϕ and ρ are parameters to be estimated, and ϵ is a white noise error term. Under the null hypothesis of a unit root ($\mathrm{H_0}$: $\phi_i = 0$ for all i), ln Z_{it} is non-stationary for all countries in the panel, and the series must be first-differenced to render it stationarity. Under the alternative hypothesis that none of the countries have a unit root (H_1: $\beta_i < 0$), ln Z_{it} is stationary around a deterministic trend for all countries in the panel.

Eq. (4) is estimated for log TFP, log DRD, log FRD, M/Y, COM and TEL, and the country-specific ADF statistics t_{iT} (the t statistic on ϕ_i in (4)) are used to calculate the average ADF test statistic ($\bar{t}_{NT}$):

$$\bar{t}_{NT}(p,\rho) = \frac{1}{N}\left(\sum_{i=1}^{N} t_{iT}(p_i,\rho_i) \right) \tag{5}$$

The modified group mean IPS statistic $\Psi_{\bar{t}}$ is formed from (5), and the mean ($E[t_{iT}(p_i,0)]$) and variance ($V[t_{iT}(p_i,0)]$) of each distribution of $t_{iT}(p_i,0)$:

$$\Psi_{\bar{t}} = \frac{\sqrt{N}\{\bar{t}_{NT}(p,\rho) - \frac{1}{N}\sum_{i=1}^{N} E[t_{iT}(p_i,0)]\}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} V[t_{iT}(p_i,0)]}} \tag{6}$$

The values for $Et_{iT}(p_i,0)$ and $Vt_{iT}(p_i,0)$ for different model specifications and lag orders are reported in IPS (1997). Since $\Psi_{\bar{t}}$ is distributed standard normal, a negative value above two leads to rejection of the null hypothesis of a unit root in favour of stationarity.

When log TFP, log DRD, log FRD, M/Y, COM, and TEL are $I(1)$, (1)–(3) can be tested for cointegration by applying the IPS test to TFP equation residuals. When the variables are cointegrated, Engle and Granger (1987) prove there exists a corresponding error-correction model (ECM) of the form:

$$\Delta \log \mathrm{TFP}_{it} = \pi_0 + \pi_1 X_{it} + \eta[\log \mathrm{TFP}_{it-1} - \lambda \mathrm{X}_{it-1}] + w_{it} \tag{7}$$

where π_0 is a constant, π_1 are the estimated short-term effects, η is the estimated coefficient for the lagged error correction term, λ is a vector of cointegrating coefficients, X contains log DRD and log FRD for (1), log DRD, ASIA log DRD, and (M/Y)log FRD for (2) and, log DRD, ASIA log DRD, (M/Y)log FRD, COM log FRD and TEL log FRD for (3), and w_t is a white noise error term. The error correction term is formed from the cointegrating residuals and η measures how changes in log TFP, log DRD, (M/Y)log FRD, COM log FRD and TEL log FRD respond to departures from the long-run equilibrium. Short-run convergence to equilibrium is assured when η is both negative and significant. Accordingly, the t-statistic on the coefficient for the lagged error-correction term η provides an additional test of cointegration (Engle and Granger, 1987).

3. Data

TFP Eqs. (1)–(3) are estimated on a sample of: seven OECD G7 economies, Canada, France, Germany, Italy, Japan, United Kingdom (UK), United States (US); eight OECD non-G7 industrialised economies, Australia, Denmark, Finland, Ireland, Netherlands, Norway, Spain, and Sweden; and five Asian countries, India, Indonesia, Singapore, South Korea and Thailand. Annual data from 1980 to 1995 are collected for exchange rates, fixed capital, GDP, labour, aggregate imports, ITT equipment and service imports, domestic R&D expenditures and prices. These data are used to construct a TFP index (1985 = 1), domestic and foreign R&D capital stocks, and measures of openness to trade. Variable definitions and data sources are described in Appendix A.

Means, standard deviations, minimum and maximum values for TFP, DRD, FRD M/Y, COM, and TEL are reported in Table 1. Since TFP is an index it is not

Table 1
Summary statistics 1980–1995

	TFP (1985 = 1)	DRD million USD	FRD million USD	*M/Y*	COM	TEL per person minutes
OECD G7						
Mean	1.0270	387,446	447,244	0.2042	0.3658	29.4627
St dev	0.1016	456,809	312,232	0.0695	0.0515	21.2028
Min	0.9180	33,891	132,780	0.0701	0.2474	0.7791
Max	1.5084	1,828,146	1,453,942	0.3451	0.4808	100.8009
OECD non-G7						
Mean	1.0045	20,147	354,506	0.3362	0.3307	42.7026
St dev	0.0760	14,707	113,353	0.1247	0.0918	27.9491
Min	0.8539	1183	205,147	0.1599	0.1594	3.4397
Max	1.3663	54,707	713,662	0.6088	0.6476	112.8743
Asia						
Mean	1.1453	7093	507,745	0.5463	0.3284	20.6394
St dev	0.2036	8010	115,488	0.6073	0.0948	50.4305
Min	0.8195	482	335,738	0.0843	0.1410	0.0123
Max	1.8330	31,443	832,151	2.1608	0.5507	258.8314

possible to compare absolute values for TFP across country groupings. The mean Asian TFP value of 1.1453 suggests TFP growth for the period 1980–1995 was greater for Asian economies. Thailand has the highest rate of TFP growth for sample countries at 4.9% per annum (p.a.), followed by South Korea (4% p.a.), Germany (2.7% p.a.), Ireland (2.5% p.a.), India (2.4% p.a.) and Indonesia (2.4% p.a.). As expected domestic R&D activity is substantially greater for G7 economies. The US has by far the largest domestic R&D stock in the world at 1995 of 1828 billion US dollars (USD). Domestic R&D activity is relatively low in developing Asian economies, with mean DRD about 2% of OECD non-G7 mean DRD, and about a third non-G7 mean DRD. Foreign R&D stocks are reasonably similar across G7, non-G7 and Asian economies, as is the share of computers and communications equipment to service imports. The relatively large share of aggregate imports in GDP and outgoing IMTS minutes per person in Asia is largely attributable to Singapore. Singapore is an important trade entrepot in the Asia-Pacific. At 1995, Singapore had the largest share of aggregate imports to GDP and per capita outgoing IMTS minutes for the sample.

Plots of log TFP, log DRD, log FRD, M/Y, COM and TEL for the period 1980–1995 are provided in Appendix B. Fig. B1 through B6 show a steady increase in most series through time. The IPS panel unit root test is applied to all series. Initially, the ADF regressions (4) are estimated for log TFP, log DRD, log FRD, M/Y, COM, and TEL for each country for the period 1980–1995.[7] The ADF

[7] Due to the relatively short span of data in the sample, the number of lagged differenced terms in the ADF auxiliary regression (4) is set a priori at two to eliminate autocorrelation.

Table 2
IPS panel unit root tests

	ADF test statistics for each series and country (t_{iT})					
Country	log TFP	log DRD	log FRD	M/Y	COM	TEL
Canada	−2.649	−0.583	−1.336	−0.002	−1.785	−1.006
France	−3.726	−2.314	−1.878	−2.474	−1.966	−2.706
Germany	−1.685	−1.903	−2.346	−2.778	−1.704	−0.567
Italy	−2.668	−1.483	−2.043	−0.411	−2.682	−1.408
Japan	−1.488	−1.731	−2.046	−1.842	−4.384	−2.348
UK	−1.551	−3.695	−1.158	−2.532	−2.734	−0.534
US	−2.472	−0.401	−3.084	−1.719	−2.829	1.194
Australia	−2.757	−4.606	−1.718	−1.678	0.812	−1.470
Denmark	−3.186	−0.753	−0.176	−1.831	−1.892	−2.329
Finland	−1.908	−1.858	−2.513	0.197	−0.551	−0.226
Ireland	−2.302	0.060	−2.631	−0.373	−1.142	−2.885
Netherlands	−2.619	−3.230	−1.197	−3.273	−1.925	−2.255
Norway	−3.221	−1.423	−2.707	−2.365	−2.184	−0.599
Spain	−3.787	−5.227	−1.217	−2.650	−3.783	−2.395
Sweden	−2.787	−1.711	−1.922	−1.809	−2.105	−2.463
South Korea	−0.587	−1.862	−2.975	1.113	−4.334	4.342
Singapore	−1.719	−1.078	−1.763	−3.547	−1.332	0.605
India	−2.858	−2.853	−1.423	0.560	−1.414	0.684
Indonesia	−1.082	−7.451	−2.527	−1.453	−2.334	−7.197
Thailand	−2.075	−2.815	−2.794	−1.851	−1.026	−1.862
($\bar{t}_{NT}$):	−2.356	−2.346	−1.973	−1.536	−2.065	−1.271
$\Psi_{\bar{t}}$	**−1.570**	**−1.524**	**0.116**	**2.035**	**−0.289**	**3.198**

test statistics suggest exclusion of the deterministic trend results in omitted variable bias. ADF test statistics with trend for these series by country are reported in Table 2. Only ten of the 120 (20 countries and six data series) country-specific ADF statistics reject the hypothesis of a unit root for log TFP, log DRD, log FRD, M/Y, COM and TEL. These individual country ADF statistics are used to calculate the average ADF test statistic across all countries according to (5), and the IPS panel unit root statistic using the rule (6). The IPS statistics, reported in the last row of Table 2, cannot reject the null hypothesis that each of the series in the panel has a unit root.

4. TFP equation estimation

The IPS group mean panel unit root tests indicate that log TFP, log DRD, log FRD, M/Y, COM and TEL are difference-stationary.[8] To test for cointegration the IPS panel unit root test is applied to the residuals formed from the estimation of

[8] Further testing (not reported here) shows that Δlog TFP, Δlog DRD, Δlog FRD, $\Delta M/Y$, ΔCOM and ΔTEL are stationary.

country-specific TFP Eqs. (1) through (3), respectively.[9] Country-specific ADF test statistics are reported in Table 3. Of the 60 (20 countries and three TFP equations) country-specific ADF test statistics report only one rejection of the null hypothesis of no cointegration - India in Eq. (1). However, more powerful IPS test statistics, reported in the last row of Table 3, conclusively reject the null hypothesis of no cointegration for TFP Eqs. (1) through (3). Further, both the ADF unit root test of pooled residuals, and the *t*-statistic on the lagged residuals from the TFP ECM, are significant and also reject the null hypothesis of no cointegration (see Table 4). In summary, both the panel and pooled residual unit root tests find a cointegrating relationship between: (1) log TFP, log DRD and log FRD; (2) log TFP, log DRD, ASIA log DRD and (M/Y) log FRD; and (3) log TFP, log DRD, ASIA log DRD, (M/Y)log FRD, COM log FRD and TEL log FRD.

Model estimates for the cointegrating TFP Eqs. (1) through (3) are reported in

Table 3
IPS panel cointegration tests

Country	ADF test statistics for TFP equation residuals for each country (t_{iT})		
	(1)	(2)	(3)
Canada	−2.580	−2.650	−3.362
France	−3.045	−2.430	−1.859
Germany	−1.494	−1.713	−2.115
Italy	−1.941	−2.186	−2.115
Japan	−2.134	−2.102	−2.489
UK	−2.286	−2.220	−1.784
US	−2.421	−1.946	−3.071
Australia	−3.230	−2.737	−2.429
Denmark	−1.906	−3.483	−2.992
Finland	−2.510	−3.032	−3.600
Ireland	−2.182	−2.583	−2.299
Netherlands	−2.903	−1.423	−2.569
Norway	−2.714	−2.385	−2.445
Spain	−2.334	−3.151	−3.164
Sweden	−2.726	−3.443	−3.469
South Korea	−2.186	−1.633	−1.808
Singapore	−1.876	−1.963	−3.407
India	−4.068	−3.534	−3.330
Indonesia	−0.962	−1.599	−2.195
Thailand	−2.765	−2.969	−2.005
$(\bar{t}_{NT})$:	−2.413	−2.459	−2.625
$\Psi_{\bar{t}}$	**−4.420**	**−4.618**	**−5.334**

[9] For the purpose of calculating IPS test statistics, the interactive dummy variable ASIA is excluded from the estimation of country-specific TFP Eqs. (1) through (3) as it cannot provide a common estimate of the difference between Asian and OECD economy TFP elasticities.

Table 4
TFP equation estimation results

Independent variable	(1)	(2)	(3)
CONSTANT	−3.249	−1.312	−0.504
log DRD	0.168	0.108	0.016
ASIA log DRD	–	0.186	0.257
logFRD	0.100	–	–
(M/Y)log FRD	–	0.031	0.034
COM log FRD	–	–	0.022
TEL log FRD	–	–	0.001
Standard error	0.079	0.073	0.070
R^2	0.584	0.652	0.677
Adjusted R^2	0.555	0.626	0.651
Cointegration tests			
ADF	−3.509[a]	−4.280[a]	−4.574[a]
IPS	−4.420[a]	−4.618[a]	−5.334[a]
ECT	−2.351[a]	−2.009[a]	−2.737[a]

[a] Denotes significance at the 5% level. ADF is the ADF test for a unit root in the residuals of the pooled TFP equations. IPS is the IPS panel test for a unit root in the residuals of the country-specific TFP equations. ECT is the *t*-statistic on the coefficient for the lagged error-correction term in the ECM.

Table 4 (coefficient estimates for country-specific intercept terms are reported in Appendix C).[10] Cointegration tests and coefficient estimates confirm the existence of a positive long-run cointegrating relationship between national productivity and R&D. Coefficient estimates for log DRD and log FRD in TFP Eq. (1) are similar to those of Coe and Helpman (1995) (Table 3; Eq. 1). The positive sign for ASIA log DRD in (2) and (3) (0.186 and 0.257, respectively) indicate that domestic R&D impacts on Asian TFP, and the effect of domestic R&D on TFP is greater for Asian economies. The positive estimates for (M/Y)log FRD in (2) and (3) (0.031 and 0.034, respectively) on TFP increases with the share of aggregate imports in GDP. Coefficient estimates for COM log FRD (0.022) and TEL log FRD (0.001) in (3) indicate that TFP increases with the share of communications and computer equipment imports in service trade, and outgoing per capita IMTS minutes.

Table 5 reports TFP elasticities for the year 1995. Unlike Coe and Helpman (1995) the elasticity estimates reported here indicate that domestic R&D is an important source of TFP growth for developing Asian economies. The elasticity of Asian economy TFP for own R&D is similar across (2) and (3), and suggests that a 1% increase in own R&D leads to a 0.27–0.29% increase in national output. This estimate is nearly three times the magnitude of the corresponding OECD elasticity of 0.1080. This finding suggests that domestic R&D is subject to diminishing returns.

[10] The standard errors for the estimated coefficients are not reported as they are generally biased and their distribution is not asymptotically normal.

Table 5
TFP elasticity's with respect to R&D 1995

Country	1995 values for:			Elasticity of TFP with respect to:			
	M/Y	COM	TEL	DRD Eq. (2)	FRD	DRD Eq. (3)	FRD
Canada	0.3451	0.4619	100.8009	0.1080	0.0107	0.0157	0.0278
France	0.2049	0.3720	49.4676	0.1080	0.0064	0.0157	0.0180
Germany	0.2228	0.3795	64.0205	0.1080	0.0069	0.0157	0.0197
Italy	0.2312	0.3307	33.2838	0.1080	0.0072	0.0157	0.0171
Japan	0.0792	0.3831	12.9888	0.1080	0.0025	0.0157	0.0118
UK	0.2903	0.3200	69.4993	0.1080	0.0090	0.0157	0.0210
US	0.1303	0.3258	61.0444	0.1080	0.0040	0.0157	0.0152
Australia	0.2033	0.2740	51.4608	0.1080	0.0063	0.0157	0.0160
Denmark	0.2939	0.2463	101.3588	0.1080	0.0091	0.0157	0.0215
Finland	0.2998	0.4869	60.9233	0.1080	0.0093	0.0157	0.0245
Ireland	0.6088	0.6476	112.8743	0.1080	0.0189	0.0157	0.0416
Netherlands	0.4629	0.4166	94.1256	0.1080	0.0144	0.0157	0.0305
Norway	0.3243	0.2427	100.2481	0.1080	0.0101	0.0157	0.0224
Spain	0.2342	0.4339	27.1217	0.1080	0.0073	0.0157	0.0190
Sweden	0.3643	0.3877	99.1052	0.1080	0.0113	0.0157	0.0268
South Korea	0.3422	0.3657	12.3577	0.2940	0.0106	0.2725	0.0204
Singapore	1.5012	0.3220	258.8314	0.2940	0.0466	0.2725	0.0739
India	0.1498	0.2931	0.3686	0.2940	0.0047	0.2725	0.0115
Indonesia	0.2745	0.4473	1.0607	0.2940	0.0085	0.2725	0.0191
Thailand	0.4840	0.3080	3.7363	0.2940	0.0150	0.2725	0.0235
Full sample	0.3523	0.3722	65.7339	0.1545	0.0109	0.1545	0.0241
OECD G7	0.2148	0.3676	55.8722	0.1080	0.0067	0.0157	0.0187
OECD non-G7	0.3489	0.3920	80.9022	0.1080	0.0108	0.0157	0.0253
Asia	0.5503	0.3472	55.2709	0.2940	0.0171	0.2725	0.0297

Since coefficient estimates for (M/Y)log FRD are positive and similar across (2) and (3), the inclusion of COM log FRD and TEL log FRD increases the elasticity of TFP with respect to FRD. The more open an economy to aggregate and ITT trade the larger is the impact of foreign FRD on TFP. The inclusion of ITT variables in TFP elasticity calculations in (3) sees the elasticity of OECD TFP with respect to own DRD decrease substantially from 0.168 to 0.108, whilst TFP elasticities with respect to foreign R&D increase in magnitude for all countries (from 0.01 to 0.0187, 0.0257 and 0.0297, respectively). Thus omission of COM log FRD and TEL log FRD from the TFP equation may lead to their affects being attributed to other sources.

5. Conclusions

This paper examines the role R&D plays in technology progress for a sample of 15 OECD and five Asian economies from 1980 to 1995. An empirical model is estimated which relates TFP to domestic and foreign R&D activity, trade, and ITT. Panel unit root tests of TFP equation residuals indicate the existence of a long-run cointegrating relationship between national productivity and R&D activity. Further, TFP equation estimation shows that domestic R&D is an important source of TFP growth and that TFP is positively related to the foreign R&D activity of their trading partners in both OECD and Asian economies. Model estimates confirm the qualitative conclusion of Coe et al. (1997) that developing Asian economies (in the South), which have relatively low levels of investment in R&D, benefit from foreign R&D spillovers from industrialised OECD economies (in the North). On average, a 1% increase in foreign R&D capital stock raises Asian national output by 0.03%. Model estimates also show that the more open an economy the greater is the impact of foreign R&D on productivity. Not surprisingly, in the emerging global information economy, openness to trade in ITT equipment and services are an important channel for the international transfer of R&D. Further, this study demonstrates that Coe and Helpman's (1995) TFP estimating equation specification may provide a misleading view of the impact of R&D spillovers on TFP growth. Finally, the collection of own R&D data for developing economies, other than Asian, would permit the examination of a richer set of potential relationship between TFP and domestic R&D.

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Appendix A. Data definitions and sources

The construction of domestic and foreign R&D capital stocks follows Coe et al. (1997). National R&D expenditures are obtained from the OECD (1996b and 1997), Korean Ministry of Science and Technology (1997), UNESCO (various issues), Singapore National Science and Technology Board (1997), Indonesian Ministry of Industry and Trade (1997), and the Thai Office of Policy and Planning (1997). These data are deflated by the R&D price deflator (PR):

$$\mathrm{PR} = 0.5P + 0.5W \qquad \text{(A.1)}$$

where P is the GDP price deflator and W is the average wage index. GDP deflators are obtained from the World Bank (1999) and the International Monetary Fund (IMF, 1997). An index for non-agricultural wage activity is obtained from International Labour Office (ILO, various issues) and the IMF (1997). Since wage index data for Indonesia is incomplete the GDP deflator is used for this country.[11]

Domestic R&D capital stocks (DRD) are calculated using the perpetual inventory method:

$$\mathrm{DRD}_{it} = (1 - d)\mathrm{DRD}_{it-1} + R_{it-1} \tag{A.2}$$

where R_{it-1} is previous period new domestic R&D expenditure for country i, and δ is the depreciation rate (fixed at 5%). The initial value for DRD (DRD_0) is calculated by:

$$\mathrm{DRD}_0 = R_0/(g + \delta) \tag{A.3}$$

where g is the annual average growth of domestic R&D expenditure, and R_0 is the initial value of R&D expenditure. Domestic R&D capital stocks are converted to USD using exchange rates obtained from the World Bank (1999). Foreign R&D capital stocks (FRD) for country i are calculated by weighting the $j \neq i$ country domestic R&D capital stocks by i's bilateral import shares with the $j \neq i$ countries. Import share data are obtained from the IMF (various issues).

The TFP index is calculated from:

$$\mathrm{TFP} = \frac{Y}{K^{1-\beta}L^{\beta}} \tag{A.4}$$

where Y is output, K is fixed capital stock, L is labour force and β is the labour share of output. GDP data is obtained from the IMF (1997) and World Bank (1999), whilst capital stock per worker in 1995 prices is obtained from Summers and Heston (1991). All series are complete for 1980 through 1992 except Indonesia, South Korea and Singapore. The perpetual inventory method is used to interpolate missing data points, with estimation using gross domestic fixed investment data from the World Bank (1999) and a constant depreciation rate of 15% (Griliches, 1990). Per worker capital stock are multiplied by total labour force data from the World Bank (1999) to obtain aggregate capital stock.

Finally, aggregate import to GDP shares and communications and computer equipment imports to GDP shares are obtained from the World Bank (1999), whilst outgoing IMTS minutes per person are obtained from the ITU (1998).

[11] Some R&D expenditure series are not complete for the period 1980–1995. To complete these series an equation is estimated regressing the logarithms of real R&D on real output and investment to interpolate missing values (Coe and Helpman, 1995).

Appendix B. Data Plots 1980–1985

Figs. B1–B18.

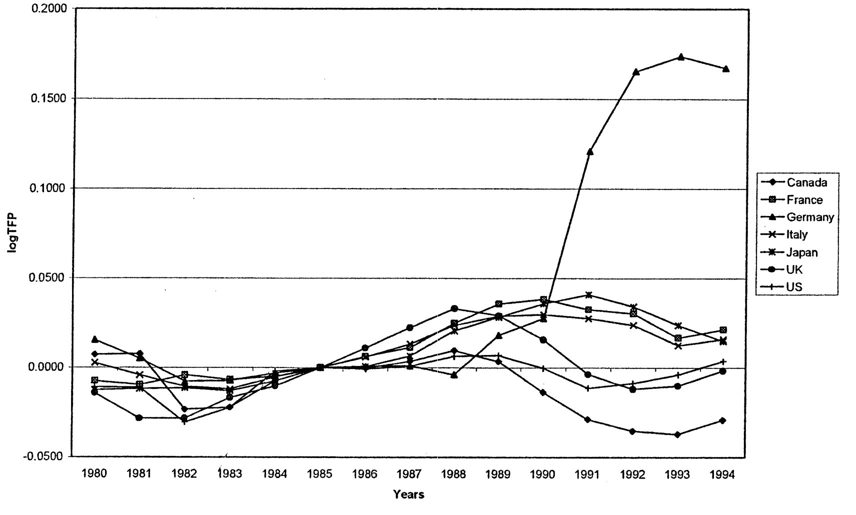

Fig. B1. OECD G7 log TFP.

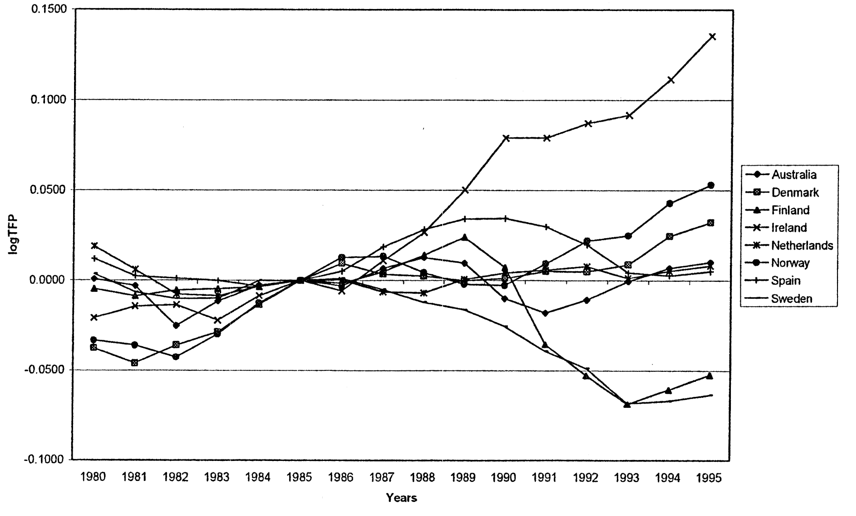

Fig. B2. OECD non-G7 log TFP.

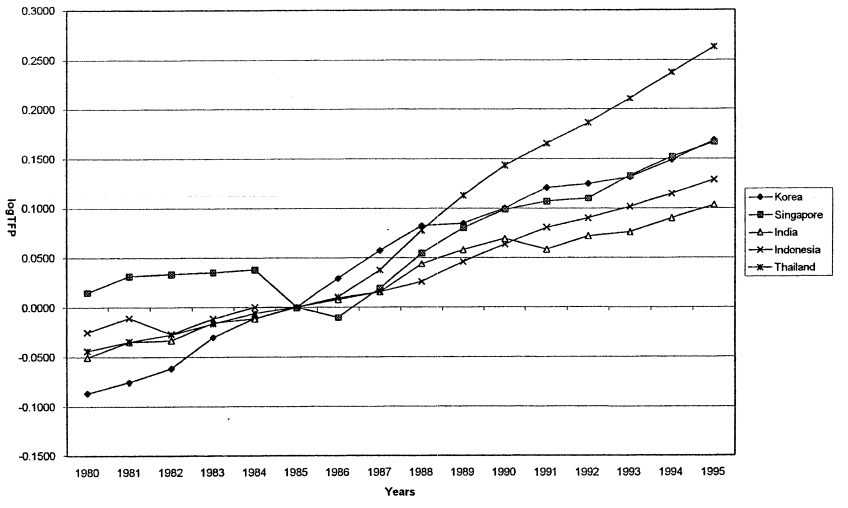

Fig. B3. Asian log TFP.

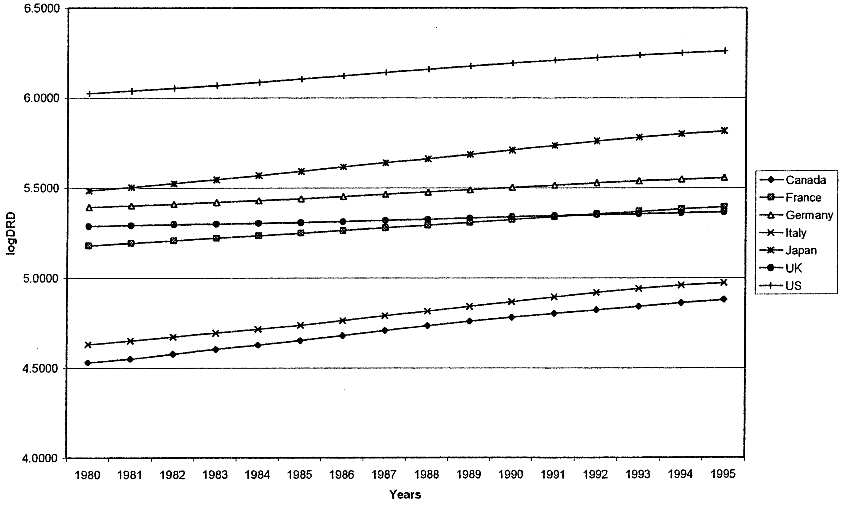

Fig. B4. OECD G7 log DRD.

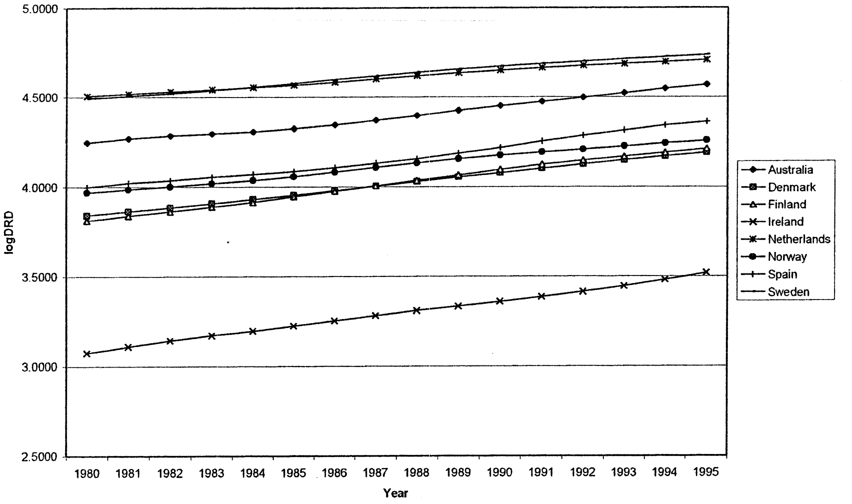

Fig. B5. OECD non-G7 log DRD.

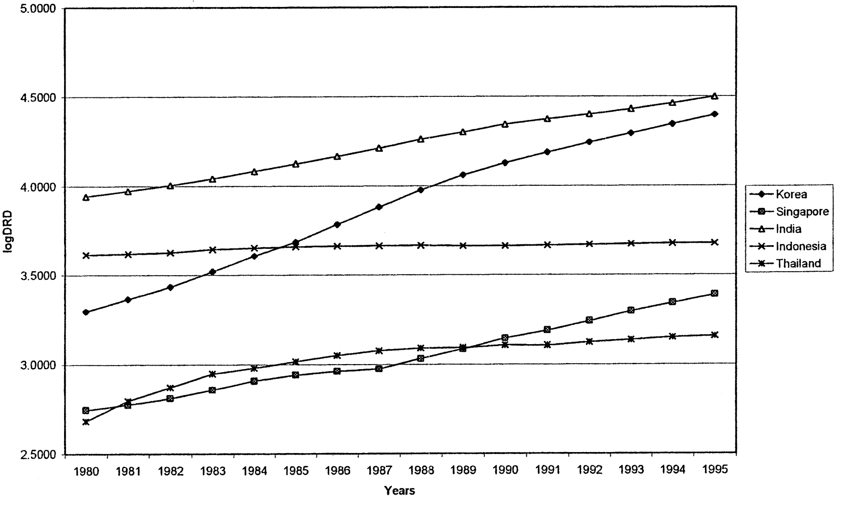

Fig. B6. Asian log DRD.

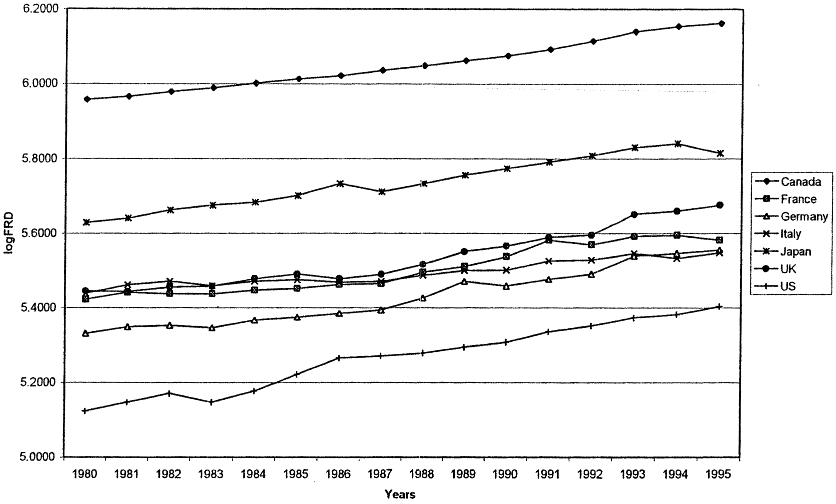

Fig. B7. OECD G7 log FRD.

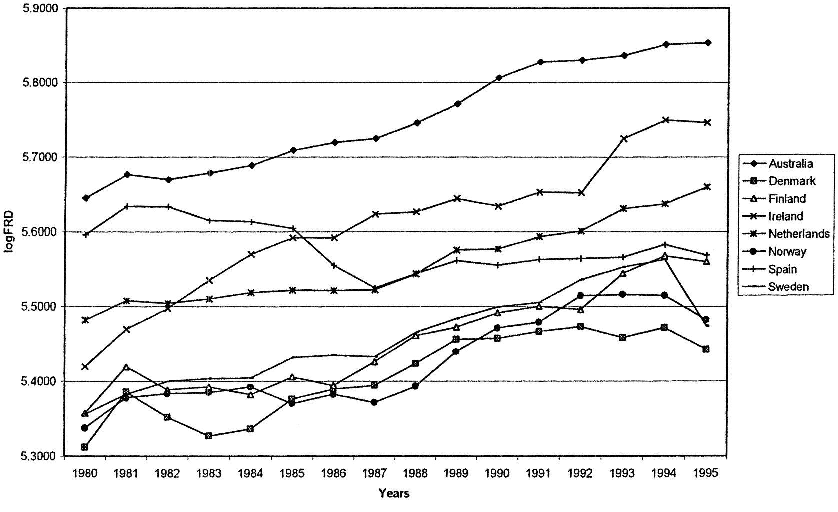

Fig. B8. OECD non-G7 log FRD.

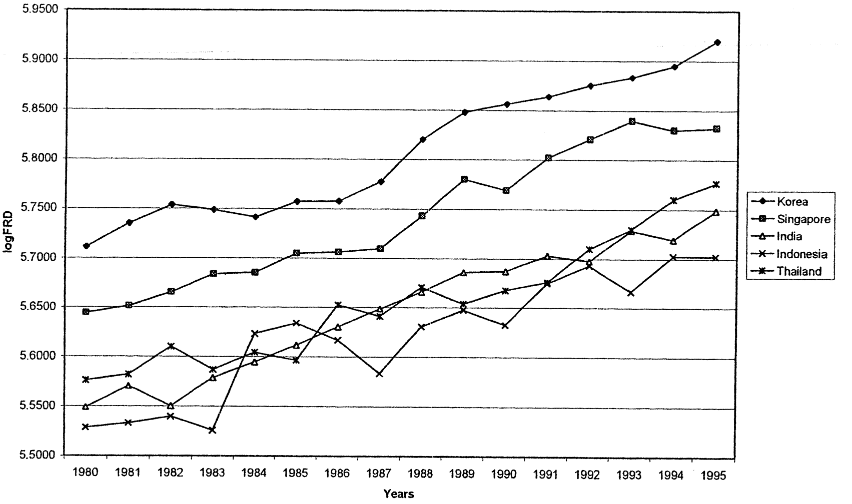

Fig. B9. Asian log FRD.

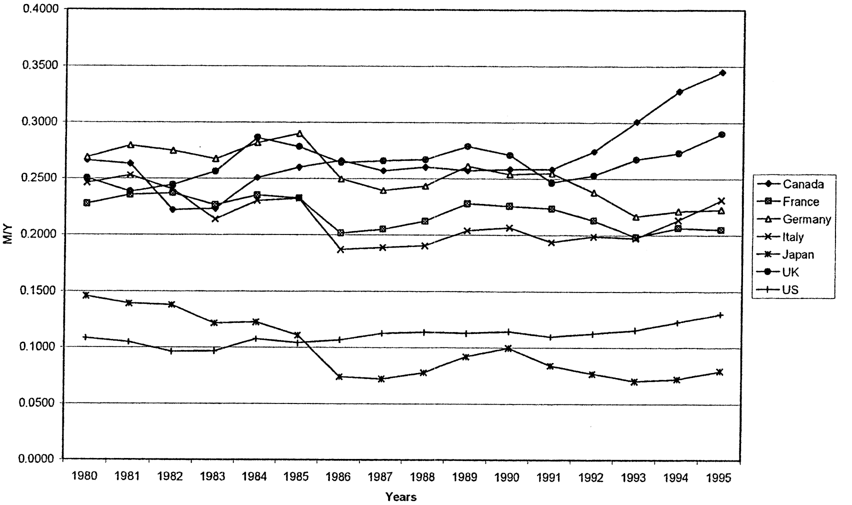

Fig. B10. OECD G7 M/Y.

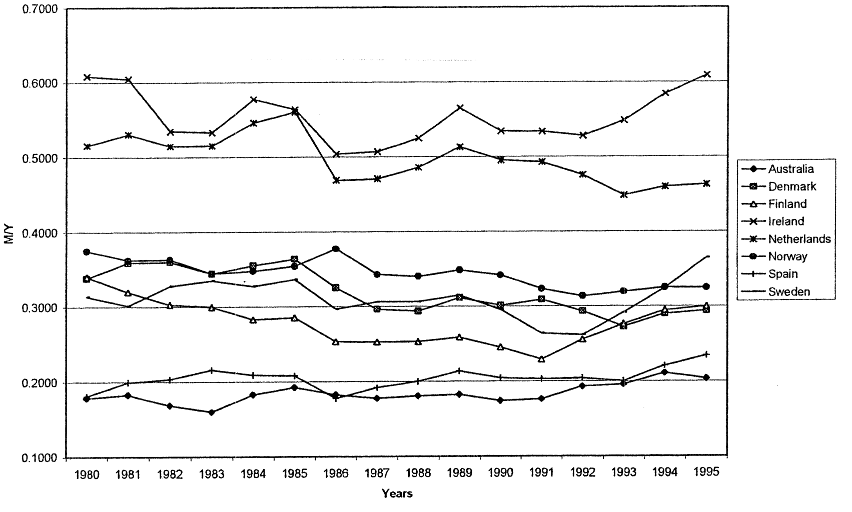

Fig. B11. OECD non-G7 M/Y.

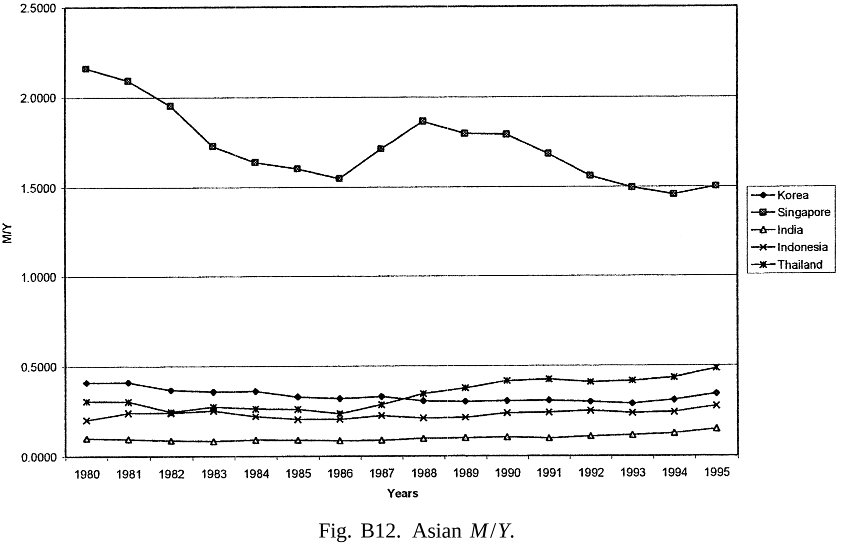

Fig. B12. Asian M/Y.

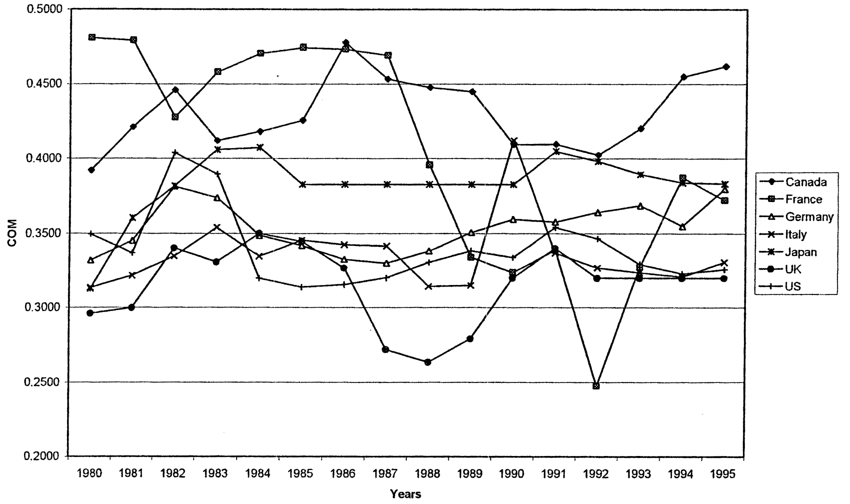

Fig. B13. OECD G7 COM.

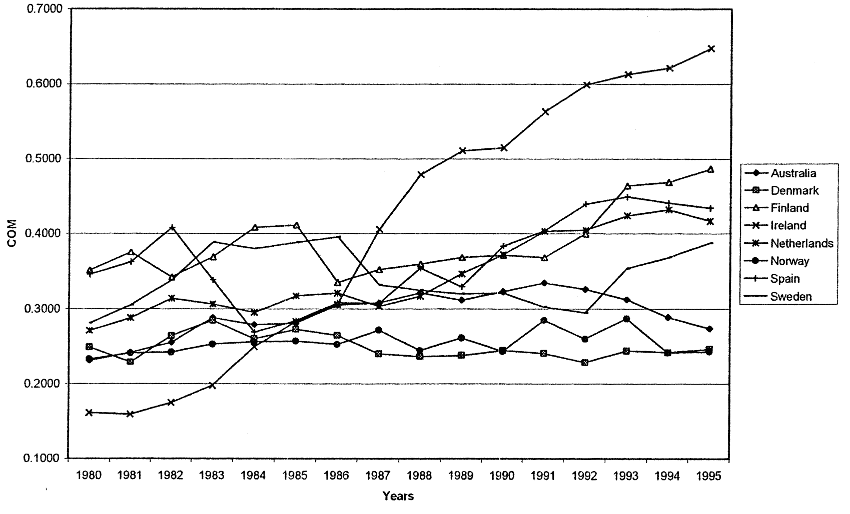

Fig. B14. OECD non-G7 COM.

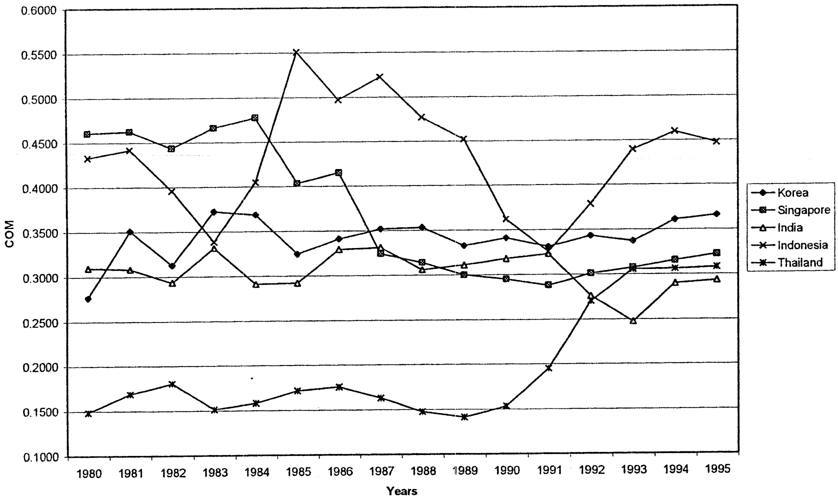

Fig. B15. Asian COM.

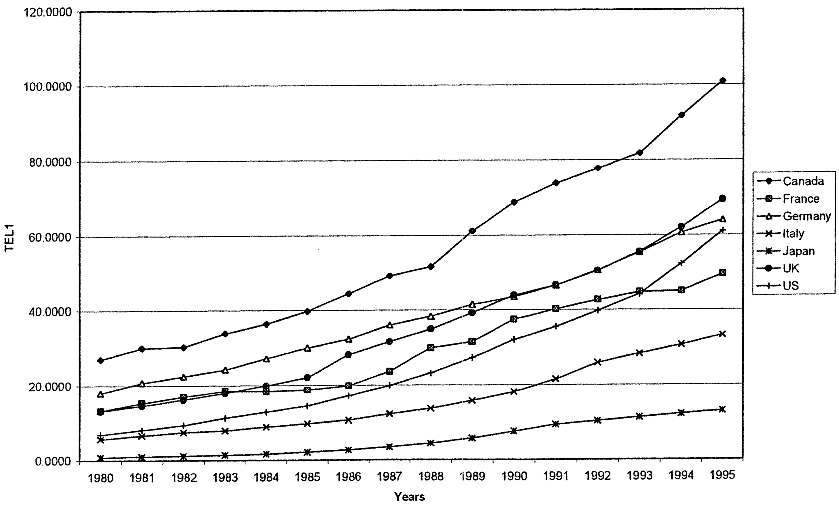

Fig. B16. OECD G7 TEL.

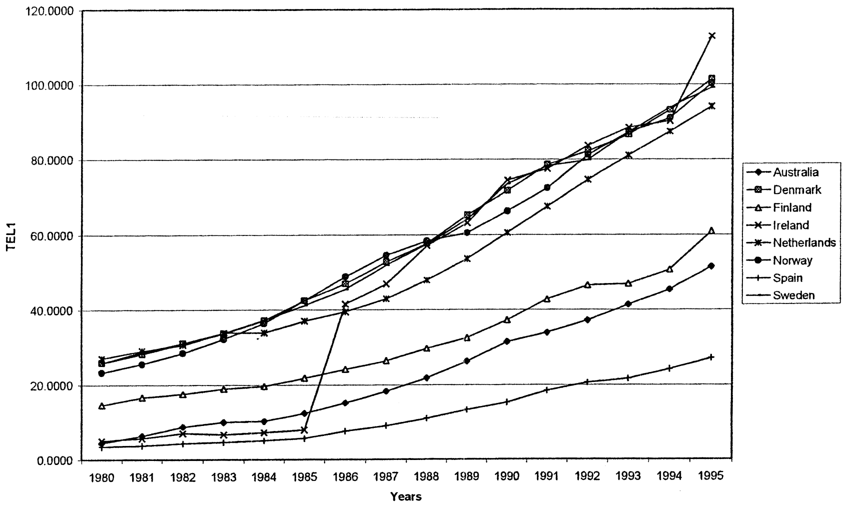

Fig. B17. OECD non-G7 TEL.

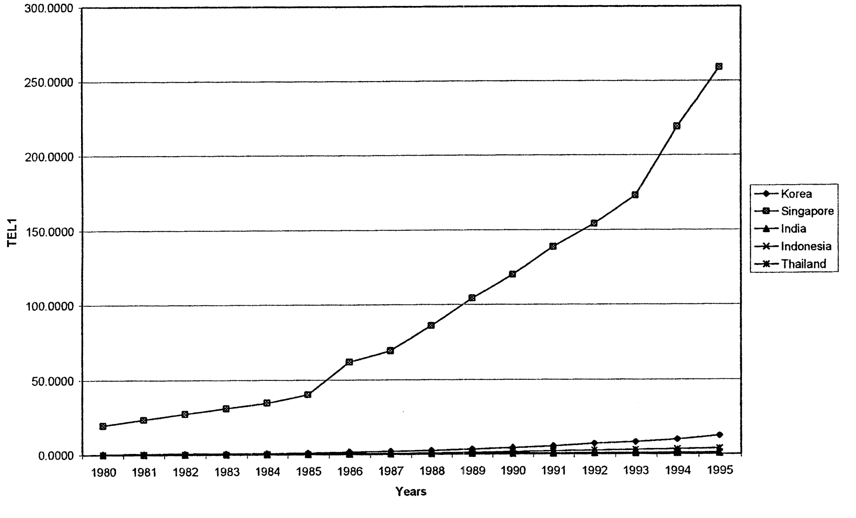

Fig. B18. Asian TEL.

Appendix C. Country intercepts for (1) through (3)

Country-specific intercept	(1)	(2)	(3)
France	−0.036	−0.054	0.115
Germany	0.002	−0.019	0.196
Italy	0.147	0.063	0.158
Japan	−0.239	−0.105	0.164
UK	−0.090	−0.114	0.080
US	−0.355	−0.264	0.116
Australia	0.215	0.142	0.153
Denmark	0.437	0.184	0.102
Finland	0.400	0.173	0.073
Ireland	0.764	0.359	0.072
Netherlands	0.187	−0.023	−0.013
Norway	0.407	0.163	0.100
Spain	0.377	0.227	0.180
Sweden	0.148	−0.006	0.013
South Korea	0.516	−1.336	−2.076
Singapore	0.898	−1.296	−2.215
India	0.375	−1.516	−2.213
Indonesia	0.623	−1.161	−1.926
Thailand	0.962	−0.678	−1.413

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