Catching Up to the Technology Frontier: The Dichotomy between Innovation and Imitation

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CATCHING UP TO THE TECHNOLOGY FRONTIER: THE DICHOTOMY BETWEEN INNOVATION AND IMITATION

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Abstract: Using data for 55 developing and developed countries, this research examines the roles of technology transfer, research intensity, educational attainment and the ability to absorb foreign technology in explaining cross-country differences in productivity growth. The results show that innovation is an important factor for growth in OECD countries whereas growth in developing countries is driven by imitation. Furthermore the interaction between educational attainment and the distance to the frontier is a significant determinant of growth in the overall sample.

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Keywords: R&D; endogenous growth theory; absorptive capacity

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1. Introduction

Endogenous growth theory has increasingly focused on the roles of technology transfer and absorptive capacity in explaining productivity growth across countries (Eaton and Kortum, 1999; Howitt, 2000; Xu, 2000; Keller, 2002a, b; Griffith et al., 2003, 2004; Hu et al., 2005; Kneller, 2005; Kneller and Stevens, 2006; Madsen et al., 2009). Countries that are technologically backward may have greater potential for growth than more advanced countries (Gerschenkron, 1962), mainly because of their lower effective costs in creating new and better products (Howitt, 2000). However, backwardness does not automatically translate into higher growth. First, given that technological knowledge is tacit, adaptors need to spend time and resources to master the technologies that are developed elsewhere (Howitt, 2005). Second, the increasing complexity of products requires a large investment in knowledge in order to take advantage of the technology developed elsewhere (Howitt, 2005). Third, factory workers, technicians, engineers, and managers cannot adapt new technologies without adequate training (Hobday, 2003).

This research explores the effects of R&D intensity, educational attainment, distance to the technological frontier and their interactions on TFP growth in developed and developing countries. Specifically, we test the importance of research and education in creating new knowledge or in imitating technologies that are developed elsewhere. This provides some insights into whether investments in R&D and education have resulted in more innovative or imitative activity. Despite the importance of these issues for growth in developing countries, empirical studies on the effects of the interaction between distance to the frontier and R&D intensity or educational attainment have focused exclusively on OECD countries (e.g., Griffith et al., 2003, 2004; Kneller, 2005; Kneller and Stevens, 2006), which is probably due to the difficulty associated with obtaining R&D data for developing countries.

Developing countries that are far from the technological frontier may derive more benefits from investment in knowledge than OECD countries. By acquiring foreign technology, they may be able to obtain additional economies of scale through leapfrogging over the early stages of development (Gerschenkron, 1962). As shown by Coe et al. (1997), TFP in developing countries is positively and significantly related to international R&D spillovers from advanced economies. Moreover, Savvides and Zachariadis (2005) argue that TFP growth for developing countries that are relatively close to the frontier is likely to be significantly boosted by technological diffusion from the frontier countries. These insights suggest that more attention should be paid to the roles played by R&D and educational attainment for growth in developing countries.

The term "absorptive capacity" captures the idea that the benefit of technological backwardness enjoyed by a laggard country can be enhanced if it is sufficiently capable of exploiting the technology developed in the frontier countries (Abromovitz, 1986). Although countries may be endowed with different abilities in adopting new technologies, more investment in domestic R&D and education may generally increase their capacity to effectively absorb foreign technology. Hobday (2003) shows that a common factor behind the success of the NICs was large investment in training and R&D in order to adapt those technologies that were developed in more advanced countries.

New technology is often complex and is embedded in physical capital that creates significant interdependence between the leader and follower countries. Effective transfer of foreign technology may be hindered unless the follower countries undertake adequate local R&D investments so that knowledge developed in the frontier countries can be appropriately adapted to local conditions (Verspagen, 1991; Fagerberg, 1994; Aghion and Howitt, 2005; Howitt, 2005). Furthermore, higher educational attainment by the work force may also facilitate the assimilation of foreign technology (Nelson and Phelps, 1966; Abromovitz, 1986; Cohen and Levinthal, 1989; Benhabib and Spiegel, 1994, 2005; Engelbrecht, 1997). These investments are essential for the laggards to upgrade their technology, move up the development ladder, and catch up to the frontier. Hence, R&D and educational attainment have two facets with respect to the production of knowledge - a direct effect and an indirect effect through enhancing the ability to absorb new technology (Kneller and Stevens, 2006).

The paper is structured as follows. Section 2 briefly discusses the analytical framework which is used to guide our empirical formulation. Section 3 discusses the data and construction of the variables. The empirical estimates are obtained using the system GMM estimator for a panel of 55 countries covering the period 1970-2004. The sample is further divided into 23 OECD and 32 developing countries to gain some insights into the importance of R&D, educational attainment and absorptive capacities for TFP growth in laggard economies relative to advanced ones. The results are presented and discussed in Section 4 and robustness checks are undertaken in Section 5. The last section concludes.

2. Empirical Framework

The empirical analysis in this paper integrates the hypothesis of Nelson and Phelps (1966), which focuses on the interaction between educational attainment and distance to the frontier, with that of Howitt (2000) and Griffith et al. (2000, 2003), in which research intensity and its interaction with distance to the frontier play the key roles for growth.

First, consider the following equation that characterizes the relationship between educational attainment (*SCH*) and TFP growth ($\dot{A}_t / A_t$), as postulated by Nelson and Phelps (1966). In their model, TFP growth is an increasing function of the interaction between educational attainment and is proportional to the gap between the theoretical level of technology (T_t) and the technology in practice (A_t):

$$\frac{\dot{A}_t}{A_t} = \phi\left(SCH_t\right)\left(\frac{T_t - A_t}{A_t}\right). \qquad \phi(0) = 0, \qquad \phi'(SCH) > 0. \tag{1}$$

Allowing the gap between the actual and theoretical level of technology to influence TFP growth with a time lag, the empirical counterpart of this equation can be written as follows (Benhabib and Spiegel, 1994):

$$\frac{\dot{A}_t}{A_t} = \phi\left(SCH_t\right)\left(\frac{A_{t-1}^{\max}}{A_{t-1}}\right), \tag{2}$$

where A^{max} is TFP at the technology frontier country. This equation shows that the further a country is behind the technological frontier, the higher is its growth potential, provided that it has a sufficiently high level of educational attainment, or absorptive capacity, to take advantage of its backwardness. This reasoning follows the seminal hypothesis of Gerschenkron (1962) that backward countries possessing an educated labor force are able to take advantage of the technology developed elsewhere to catch up to the frontier. Similarly, Easterlin (1981) notes that more productive nations have used the same technology throughout history and that Japan modernized in the Meiji restoration period using western technology, suggesting that personal contacts and the availability of an educated workforce to understand new technologies have been essential for the assimilation of foreign technology. Thus, given that technology must be taught and learned, education becomes an integral part of its transfer. In other words, it is simply easier for an educated rather than an uneducated labor force to master new technologies that have been developed elsewhere.

Based on the insights from Schumpeterian growth models, the important roles of innovation and assimilation of foreign technology for growth have been further highlighted by Howitt (2000) and Griffith *et al.* (2003). They demonstrate that domestic R&D activity, in addition to stimulating

TFP growth, facilitates technology transfer. They suggest that the following specification is appropriate for testing for the influence of R&D on growth:

$$\frac{\dot{A}_t}{A_t} = \alpha\left(\frac{X}{Q}\right)_{t-1} + \beta \ln\left(\frac{A^{\max}}{A}\right)_{t-1} + \chi\left(\frac{X}{Q}\right)_{t-1} \ln\left(\frac{A^{\max}}{A}\right)_{t-1}, \tag{3}$$

where X is R&D, Q is product variety and (X/Q) is research intensity.

This Schumpeterian model maintains the scale effects that are present in the first-generation endogenous growth models. However, it deviates from them by allowing for product proliferation effects to overcome Jones' critique. Jones (1995a, b) shows that the increasing number of scientists and engineers engaged in R&D in the US since the 1950s has not been followed by a concomitant increase in TFP growth rates, thus refuting the first-generation R&D-based endogenous growth models of Romer (1990) and Aghion and Howitt (1992). To address this problem, the Schumpeterian models of Aghion and Howitt (1998) and Howitt (2000) assume that the effectiveness of R&D is diluted due to the proliferation of products as the economy expands. Thus, growth can still be sustained if R&D is kept at a fixed proportion of the number of product lines, which is in turn proportional to the size of the population along the balanced growth path.

Considering the joint effects of educational attainment and R&D, Eqs. (2) and (3) yield the following empirical specification, which is augmented to allow for the direct effects of educational attainment and several control variables:

$$\Delta \ln A_{it} = \beta_{0i} + \beta_1 \ln\left(\frac{X_{it}}{Q_{it}}\right) + \beta_2 \ln\left(\frac{A_{t-1}^{\max}}{A_{i,t-1}}\right) + \beta_3\left(\frac{X_{it}}{Q_{it}}\right)\ln\left(\frac{A_{t-1}^{\max}}{A_{i,t-1}}\right)$$

$$+\beta_4 \ln SCH_{it} + \beta_5 SCH_{it} \ln\left(\frac{A_{t-1}^{\max}}{A_{i,t-1}}\right) + \gamma' C_{it} + \varepsilon_{it}, \tag{4}$$

where C is a vector of control variables (which includes growth in trade openness, growth in FDI inflows as a percentage of nominal GDP, change in the rate of inflation, growth in financial development, and distance from the equator) and ε_{it} is a stochastic error term. Three different measures of research intensity are used and discussed in the next section. Schooling (*SCH*) is included as an additional regressor, following Benhabib and Spiegel's (1994) extension of the Nelson-Phelps model.

These are considered to be the most important control variables in cross-country growth studies (Fischer, 1993; Andrés and Hernando, 1997). Trade openness is assumed to influence growth positively because it indicates, amongst other things, low tariff and non-tariff trade barriers, increasing competition and the potential to acquire knowledge that is embedded in imported goods

(Madsen, 2009). Foreign direct investment is assumed to be growth-enhancing because of the potential positive externalities that are associated with the technologies, know-how and knowledge that are embodied in foreign investment (Savvides and Zachariadis, 2005; Keller, 2004). Inflation is bad for growth because it tends to increase required capital returns, which in turn lowers investment in R&D and fixed capital (Madsen and Davis, 2006). Furthermore, rising inflation is often an indication of macroeconomic mismanagement (Fischer, 1993; Andrés and Hernando, 1997). Growth is often assumed to be positively related to financial development as easier access to credit enables the initiation of capital intensive projects and provides funding of R&D (Aghion *et al.*, 2005; Ang and McKibbin, 2007).

Finally, a greater distance from the tropics is often considered to be positively related to growth because of a more favorable climate, higher endowment of natural resources, the absence of tropical diseases, and shorter geographic distances to the technology frontier (Rodrik *et al.*, 2004).

3. Data, graphical evidence and estimation method

The above model is estimated in five-year differences, to filter out random and cyclical fluctuations, using annual data over the period 1970-2004 for a panel of 55 countries (23 OECD countries and 32 developing countries). The countries included in the sample are listed in the notes to Table 1. The country sample has been made as large as possible to make the regressions as inclusive as possible. The criteria for inclusion are that the country has at least eight annual observations of R&D spanning at least 20 years. The sample contains a wide cross section of countries with different per capita income levels, including most OECD countries and developing countries such as Niger, Peru, Senegal, Sudan and Thailand.

Although the data are in five-year differences, the regression approach suggested by Basu *et al.* (2006) is used to ensure that all business cycle influences are filtered out. This method involves regressing income growth against input growth and cyclical changes in hours worked. Since the growth in weekly hours worked captures the influence of the business cycle on output, the residual can be interpreted as the trend growth in TFP. We use cyclical labor productivity measure as the growth in labor productivity instead of weekly hours worked, given that weekly hours worked are available mainly for OECD countries only. Furthermore, growth in weekly hours worked cannot be used as a cyclical indicator for most OECD countries because it has shown a significant declining trend during the period 1970-2004. This reduction has not been gradual but rather reflects changes in working hour regulations such as going from a six to a five-day week. Moreover, the workweek has often been permanently reduced following economic downturns, thus rendering it difficult to separate the trend from the cycle. The U.S., which is the country considered by Basu *et al.* (2006), is one of the very few OECD countries in which weekly hours worked have fluctuated around a constant level over the last four decades. TFP is recovered as the residual, *z*, from the following panel OLS regression:

$$\Delta \ln(Y/L)_{it} = \kappa_0 + \kappa_1 \Delta \ln(K/L)_{it} + \kappa_2 \Delta^2 \ln(Y/L)_{it} + dz_{it}, \qquad (5)$$

where Δ^2 signifies second differences. Here, L is labor input measured by the labor force or the labor force multiplied by annual hours worked for the countries for which annual hours are available (OECD countries), and K is the capital stock and is measured using the perpetual inventory method. The initial capital stock is estimated using the Solow model steady-state value of $I_0/(\delta+g)$, where I_0 is initial real investment, δ is the rate of depreciation, which is assumed to be 5% following Bosworth and Collins (2003), and g is the average geometric growth rate in real investment over the period 1970-2004. These data are obtained from the Penn World Table.

The following three indicators are used to measure R&D intensity, (X/Q) (see Ha and Howitt, 2007; Madsen, 2008b; Madsen *et al*., 2009): (1) the ratio of R&D scientists and engineers to the total labor force (N/L); (2) the share of R&D expenditures in GDP (R/Y);[1] and (3) the number of patent applications filed by domestic residents relative to the total labor force (P/L). Patent applications are used in preference to patents granted since the frequency of patent granting activities varies over time and across countries (Griliches, 1990; Jaffe and Palmer, 1997).

R&D data are collected from various issues of the UNESCO Statistical Yearbook and patent data are obtained from the WIPO (2007). Some missing data between years are interpolated arithmetically. The distance to the frontier ($A^{\max}/A$) is measured by the labor productivity gap in purchasing power parities between the US and the country under consideration. To mitigate the effects of the strong multicollinearity between distance to frontier and research intensity/human capital and their interactions, we use the TFP gap between the technology leader and the country under consideration as a measure of the distance to the frontier for the two interaction terms.

Educational attainment (*SCH*) is measured by the average years of schooling of the population aged 25 and over using the dataset provided by Barro and Lee (2001). Trade openness (*TO*) is measured as the sum of exports and imports over GDP using data from WDI (2007). Data for foreign direct investment are taken from the IMF (2007). The rate of inflation is measured by

[1] R&D expenditures are usually deflated by the arithmetic average of hourly labor costs and the GDP deflator (e.g., Coe and Helpman, 1995). However, this approach yields implausible movements in real R&D since labor earnings show abnormal fluctuations in several developing countries, particularly in Latin America and Africa. Therefore, we have simply used the GDP deflator to express R&D expenditures in real terms.

the growth rate of the CPI, and financial development is measured by the ratio of private credit to GDP (both are obtained from the World Development Indicators CD Rom, 2009). Following the standard practice, financial development is proxied by the ratio of private credit to GDP (see, e.g., Ang, 2008, 2010). Data for distance from the equator are obtained from the "Finance and the Sources of Growth" database compiled by the World Bank.

Table 1: Descriptive Statistics (1970-2004)

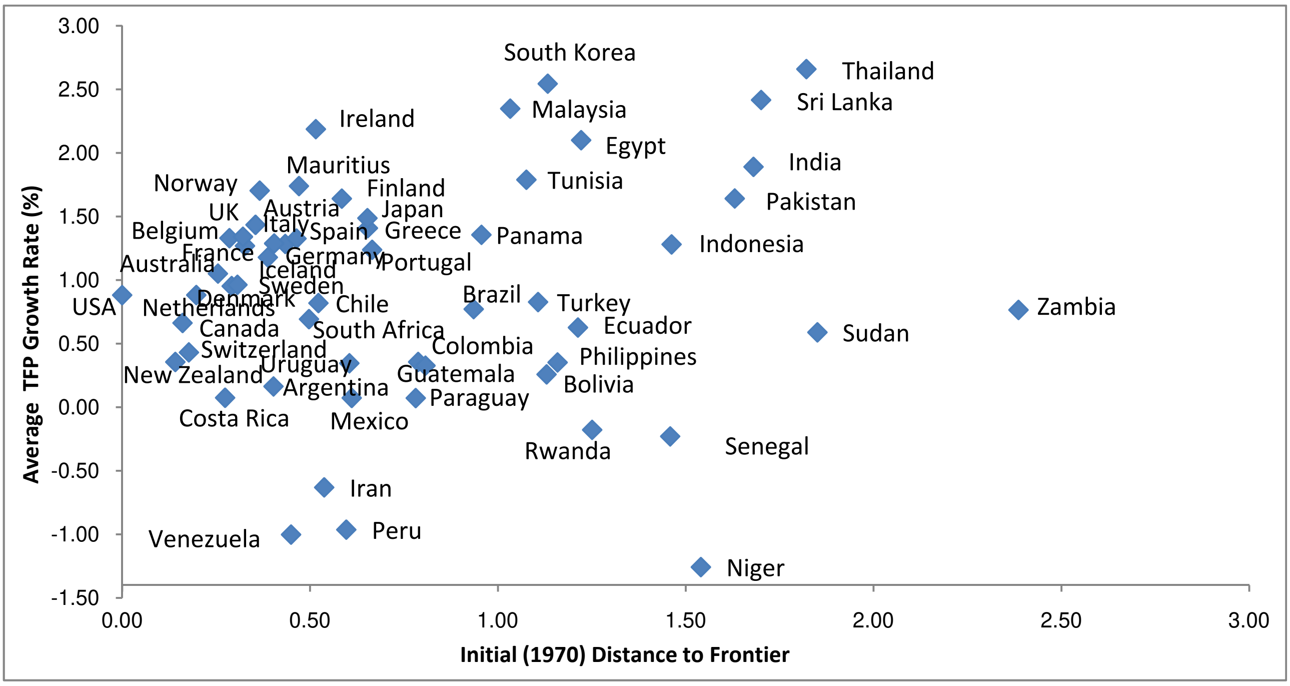
	$\Delta \ln A$	A^{US}/A	N/L	R/Y	P/L	SCH
Total sample (55 countries)						
Mean	0.90	252.36	0.23	0.99	0.04	6.11
Std. Dev.	1.96	187.98	0.26	0.84	0.07	2.88
Minimum	-7.04	100.00	0.00	0.01	0.00	0.28
Maximum	7.42	1351.06	1.52	3.97	0.54	12.29
Observations	385	385	370	296	326	384
OECD countries (23)						
Mean	1.23	139.67	0.45	1.57	0.07	8.59
Std. Dev.	1.25	30.06	0.25	0.77	0.09	1.96
Minimum	-1.72	100.00	0.05	0.18	0.00	2.65
Maximum	5.84	310.45	1.52	3.97	0.54	12.29
Observations	161	161	160	154	159	160
Developing countries (32)						
Mean	0.67	333.36	0.05	0.36	0.00	4.34
Std. Dev.	2.32	210.82	0.04	0.22	0.01	1.98
Minimum	-7.04	126.59	0.00	0.01	0.00	0.28
Maximum	7.42	1351.06	0.26	1.08	0.04	8.68
Observations	224	224	210	142	167	224

Notes: all data are expressed in percentages, except *SCH* which is expressed in years. OECD countries include: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States. Developing countries include Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Egypt, Guatemala, India, Indonesia, Iran, Malaysia, Mauritius, Mexico, Niger, Pakistan, Panama, Paraguay, Peru, the Philippines, Rwanda, Senegal, South Africa, Sri Lanka, Sudan, Thailand, Tunisia, Turkey, Uruguay, Venezuela and Zambia. All the data are measured in five-year intervals. The growth rates are annualized.

Table 1 presents the descriptive statistics for the most important variables used in the regressions. As would be expected, the mean values of all R&D intensity measures are much larger for OECD countries than for developing countries. According to the Schumpeterian theory, this implies that OECD countries have a larger growth potential than developing countries before the growth effects of the other conditional variables are accounted for. The schooling gap between OECD and developing countries is much smaller than the R&D intensity gap. The average number of years of schooling of the working age population in OECD countries is about twice that of the developing countries.

Figure 1 shows a positive relationship between initial (i.e., 1970) distance to the frontier and the average TFP growth rates over the period 1970-2004. The figure provides some evidence of gravitation towards frontier technology countries independently of educational attainment and research intensity. However, the relationship between the two variables is blurred by a high standard deviation. Despite initially being technologically backward, several countries in Latin America (e.g., Venezuela and Peru), Sub-Saharan Africa (e.g., Niger, Rwanda and Senegal) and Asia (e.g., Iran) appear to be ‘growth disasters’ with no signs of taking off. On the other hand, the eastern and South-East Asian countries such as South Korea, Thailand and Malaysia appear to be ‘growth miracles’, with strong growth records over the last few decades. High growth rates have also been observed in some South Asian countries, including India, Pakistan and Sri Lanka.

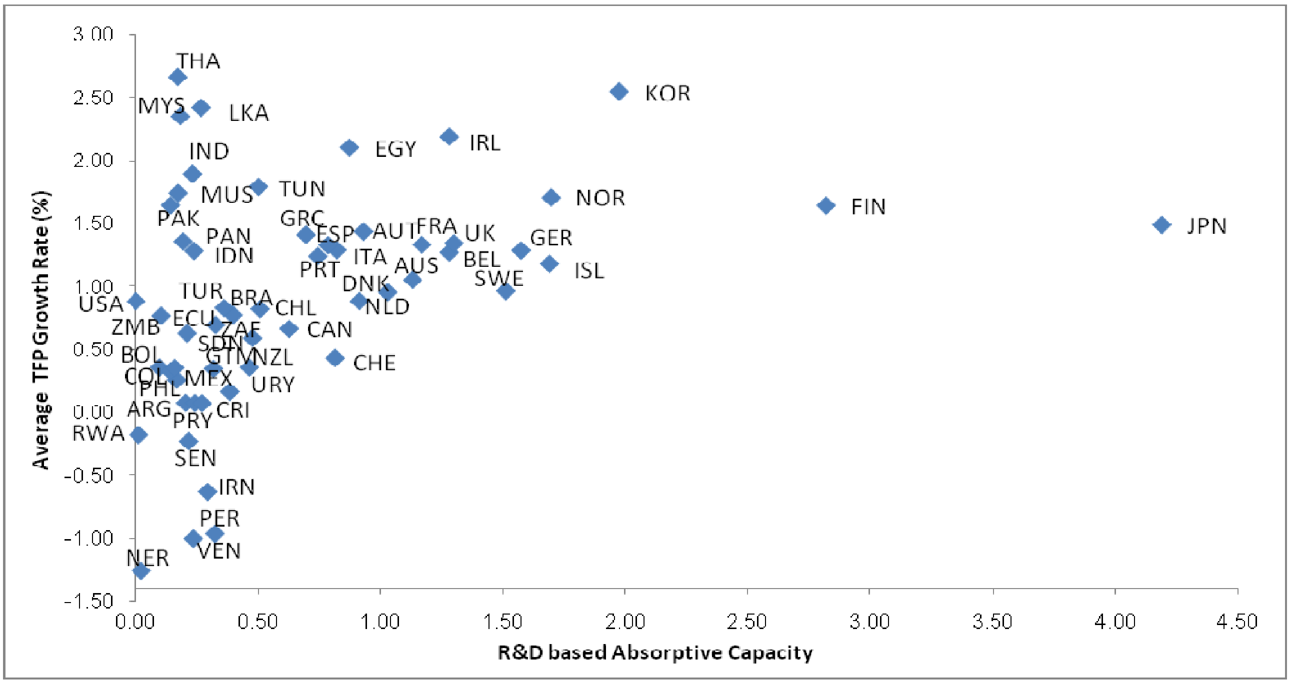
Figure 1: Initial distance to the frontier versus average TFP growth (1970-2004)



Notes: Initial distance to frontier is measured as the log of the relative TFP gap between the US and sample countries in 1970.

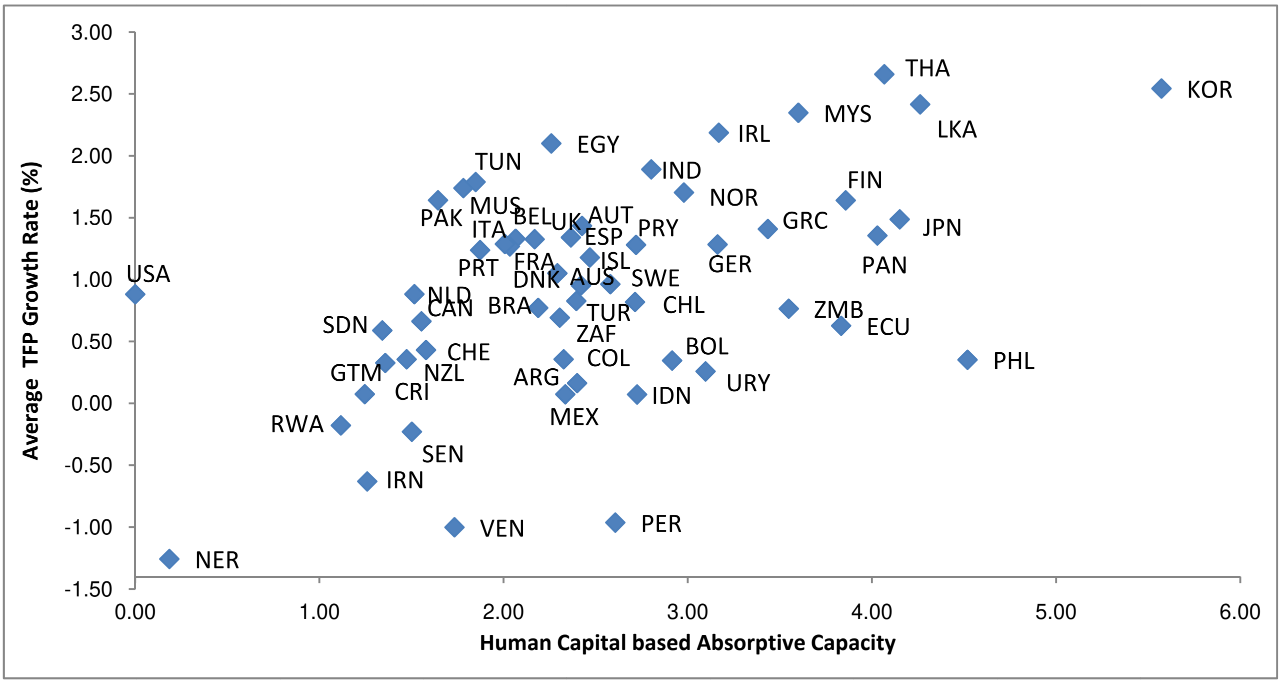
Figure 2 displays the relationship between R&D-based absorptive capacity and the average TFP growth rates, where R&D intensity is measured by *N*/*L*. There are some positive correlations between these two variables for higher values of the interaction variable; however, there appears to be no systematic relationship for very low values of the interaction term.

Figure 2: R&D-based absorptive capacity versus average TFP growth



Notes: R&D intensity is measured as the average share of scientists and engineers in the total labor force.

Figure 3: Educational attainment-based absorptive capacity versus average TFP growth



Notes: Educational attainment is measured as the average years of schooling of the total population aged 25 and over.

Finally, Figure 3 shows a positive relationship between average TFP growth rates and the interaction between educational attainment and the initial distance to the frontier. The high-growth Asian countries have experienced high growth rates in conjunction with initially large distances to the frontier and a reasonably highly educated labor force. The opposite holds true for many African and Latin American countries.

To deal with endogeneity of some of the regressors Eq. (4) is estimated using the system GMM estimator of Arellano and Bover (1995) and Blundell and Bond (1998). This technique has been widely used to deal with unobserved heterogeneity and endogeneity biases in estimation. In the presence of heteroskedasticity the system GMM estimator is more efficient than the simple IV estimator (Baum *et al.*, 2003). Furthermore, Bond *et al.* (2001) show that the system GMM estimator is the most preferred approach for estimation of empirical growth models due to its superior ability in exploiting stationarity restrictions (see also Durlauf *et al*., 2005). The system GMM estimator allows for the use of lagged differences and lagged levels of the explanatory variables as internal instruments. Moreover, the estimator also allows the inclusion of external instruments, providing a convenient way to deal with the issues of endogeneity bias (see Roodman, 2009). Consequently, the estimates in this paper are based on the system GMM estimator using internal as well as external instruments.

The following external instruments are used for research intensity, and the interaction between research intensity and the distance to the frontier: *patent protection*, *effectiveness of legislature*, and *effective executive*. These instruments are multiplied by the distance to the frontier for the interaction between research intensity and the distance to the frontier. They are based on sound economic foundations, are highly correlated with research intensity and its interaction with distance to the frontier, and are orthogonal to the residuals.[2] Tests for orthogonality are provided in the tables below ("Hansen" and "difference-in-Hansen" tests).

Patent protection is important for R&D because it encourages innovators to work on risky projects where the potential return is higher and reduces uncertainty about possible appropriation. Coe *et al.* (2009), for example, find that strong patent protection is associated with higher levels of total factor productivity, higher returns to domestic R&D and larger international R&D spillovers. Patent protection is measured by the patent rights index of Ginarte and Park (1997). The value of the index is obtained by aggregating the following five components: extent of coverage, membership in international treaties, duration of protection, absence of restrictions on rights, and statutory enforcement provisions. Each of these components is scored on a scale between 0 and 1.

Effectiveness of legislature and *effective executive* are also important for R&D because they express the quality of legislative and political institutions. For *effectiveness of legislature*, countries

[2] The correlation between the external instruments, research intensity and the distance to the frontier are 0.68-0.75 for the *patent protection* index, 0.56-0.67 for the *effectiveness of legislature* index, and 0.40-0.44 for the *effective executive* index.

that have no legislature, largely ineffective legislatures, and partly effective legislatures receive a score of 0, 1 and 2, respectively. Countries with effective legislatures are assigned a value of 3, indicating the possession of significant governmental autonomy by the legislature. *Effective executive* refers to the individual who is most influential in making decisions regarding a country's internal and external affairs. It is coded based on the following: 1 for monarch, 2 for president, 3 for premier, 4 for military and 5 for others. These are obtained from Databanks International.[3]

Although many countries have adopted good patent protection frameworks, they can be far from being effective in protecting innovators because of weak legislative and political systems. The ability of a country to implement a law depends on the quality of government agencies such as the judiciary as well as political stability. The higher the efficiency of the judicial system the better the patent protection framework, and the higher is the incentive to innovate. Political stability, accountability of government, and low corruption should also be positively related to patent rights and consequently to innovative activity. For instance, Mauro (1995) shows that investment and innovation are negatively related to corruption and bureaucratic inefficiency. Thus, to ensure that our results are robust to the choice of external instruments, the *effectiveness of legislature* index is replaced by *political rights*, *civil liberties*, *polity*, *ICRG* composite index, *law and order*, or *corruption* in the regressions. The results of using these instruments are reported in the appendix and are discussed in the next section. However, our main results continue to hold even after replacing the external instrument *effectiveness of legislature* with these indexes. This is not surprising given that the correlation coefficient between *effectiveness of legislature* and these indexes exceeds 0.7.

Moreover, to ensure that the empirical results are not driven by outliers, P/L (patent applications over the labor force) is winsorized at the top and bottom 5 percent of their distributions, i.e., values at the 5% and 95% percentiles are reduced. Winsorizing is not carried out for the regressions in which research intensity is measured by N/L (the ratio of R&D scientists and engineers to the labor force) and R/Y (the share of R&D expenditure in GDP) because the results are insensitive to whether they are winsorized.

4. Estimation Results

Three sets of regressions are considered in this section: unrestricted, β_3 (parameter of the interaction between distance to the frontier and research intensity) restricted to zero, and β_5 (parameter of the interaction between distance to the frontier and educational attainment) restricted to zero. The

[3] The data are available at http://www.databanksinternational.com/.

estimation results using *N*/*L* as the indicator of research intensity are reported in Table 2. Research intensity enters significantly in the regressions for the whole sample and the OECD sample, but is only significant in one case for the developing countries. The positive effect of R&D intensity on TFP growth for OECD countries is consistent with the findings of Griffith et al. (2003, 2004), Zachariadis (2003, 2004) and Madsen (2008b). The significance of this result is that R&D has permanent growth effects and that these will remain constant as long as the number of R&D labor is kept at a constant proportion of the labor force. The lower significance of research intensity among the developing countries compared to OECD countries is perhaps not surprising, given that R&D intensity is too low in developing countries to yield sufficiently large identifying variations in the data or to create positive externalities across a wide range of economic activities, or simply that most innovations are duplications.

The significance of distance to the frontier and its interaction with research intensity and educational attainment varies across country groups. The estimated coefficients of distance to the frontier are statistically significant in all regressions, which is in line with the results of Griffith et al. (2004), Kneller (2005), Kneller and Stevens (2006) and Madsen (2007, 2008a), among others. This finding suggests that TFP growth convergence occurs due to autonomous transfer of foreign technology. The estimated coefficients of the interaction between research intensity and distance to the frontier are significant for the developing countries but not for OECD countries. The absence of significance for OECD countries is consistent with the estimates of Madsen (2008a). Coupled with the significance of research intensity these results give very important insights into the role played by research intensity in the developed and the developing countries. R&D in OECD countries enhances productivity growth but does not enhance the absorptive capacity. In developing countries, by contrast, R&D may not have significant direct growth effects; however, it enhances the ability of countries to tap into the technology that is developed at the frontiers. In other words, R&D is of an innovative character in OECD countries, but it is predominantly of an imitative character in the developing countries. In both cases, the results give support for the Schumpeterian growth models of Howitt (2000) and Griffith *et al.* (2003). The results also corroborate the findings of Kneller (2005) for OECD countries.

Most of the estimated coefficients of educational attainment are insignificant. This result is consistent with the findings of Benhabib and Spiegel (1994), among others, who fail to find a robust direct relationship between educational attainment and growth. Intuitively, it also difficult to see why certain educational categories should induce growth permanently, given that growth is predominantly due to increasing product variety and higher product quality. Most educated people are not employed to carry out R&D and create new products and it is hard to see how certain types of education, such as law and arts, would enhance growth.

Table 2: TFP growth equations (unrestricted and restricted estimates of Eq. (4) using *N*/*L*)

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.01*** (3.05)	0.02** (2.42)	0.01*** (2.88)	0.02** (2.22)	0.01** (2.30)	0.02** (2.51)	-0.003 (-0.58)	0.01** (2.07)	-0.005 (-0.81)
$\ln(A^{max}/A_i)_{t-1}$	0.02*** (4.38)	0.01* (1.85)	0.01* (1.84)	0.03** (2.72)	0.04** (2.52)	0.05** (2.17)	0.01** (2.24)	0.01* (1.92)	0.01* (1.70)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.0005 (0.27)		-0.002 (-0.79)	-0.004 (-1.01)		-0.0002 (-0.05)	0.02** (2.15)		0.02** (2.14)
$\ln SCH_{it}$	0.007* (1.80)	-0.01 (-1.09)	-0.008 (-0.90)	-0.02 (-1.61)	-0.004 (-0.24)	-0.008 (-0.38)	0.01** (2.63)	-0.001 (-0.08)	0.01 (1.39)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.004** (2.32)	0.003** (2.07)		-0.001 (-0.30)	-0.006 (-1.15)		0.002 (0.97)	-0.001 (-0.02)
$\Delta \ln TO_{it}$	0.02*** (3.62)	0.02*** (3.85)	0.02*** (3.71)	-0.005 (-0.20)	0.01 (0.50)	0.004 (0.19)	0.02** (2.16)	0.01* (1.78)	0.02** (2.17)
ΔFY_{it}	0.15** (2.37)	0.16** (2.46)	0.20*** (3.18)	0.13 (0.88)	0.19 (1.16)	0.26** (2.65)	0.09 (1.08)	0.05 (0.85)	0.08 (0.98)
ΔINF_{it}	-0.008* (-1.80)	-0.008* (-1.85)	-0.008* (-1.78)	0.03 (0.61)	-0.03 (-0.29)	0.04 (0.68)	-0.006 (-1.31)	-0.004 (-0.73)	-0.006 (-1.29)
$\Delta \ln FD_{it}$	-0.002 (-0.49)	-0.001 (-0.23)	-0.0004 (-0.10)	-0.01 (-1.64)	-0.01 (-1.38)	-0.01 (-1.39)	0.002 (0.56)	0.003 (0.62)	0.003 (0.58)
DE_{it}	0.001 (0.09)	-0.005 (-0.20)	0.009 (0.69)	0.009 (0.35)	-0.04 (-1.35)	-0.007 (-0.34)	0.009 (0.53)	0.003 (0.12)	0.01 (0.89)
Hansen (*p*-value)	0.78	0.47	0.77	0.99	0.99	0.99	0.99	0.93	0.99
Difference-in-Hansen (*p*-value)	0.87	0.33	0.79	0.99	0.99	0.99	0.98	0.99	0.99
AR(2) (*p*-value)	0.58	0.50	0.49	0.13	0.31	0.12	0.67	0.40	0.52

Notes: Research intensity (*X*/*Q*) is measured as number of R&D scientists and engineers divided by the total labor force (*N*/*L*). *SCH* = educational attainment; A^{max} / A_i = technology gap between the U.S. and country *i*; *TO* = trade openness; and *FY* = foreign direct investment inflows as a percentage of nominal GDP; *INF* = the rate of inflation; *FD* = financial development; and *DE* = distance from the equator. The Hansen test examines the validity of the instruments with the null hypothesis that the instruments are uncorrelated with residuals. The "Difference-in-Hansen" test examines the exogeneity of the instrument subsets with the null hypothesis that the subsets of instruments are exogenous. AR(2) = test for second order serial correlation. Constants, time and country dummies are not reported due to space considerations. In most cases, 2nd and 3rd lags of the explanatory variables are taken as instruments for the differenced equation whereas 1st differences of the explanatory variables are taken as instruments for the level equation. The regressions also include three external instruments, as described in the main text. The numbers in parentheses are *t*-statistics and are based on robust standard errors. *, ** and *** denote 10%, 5% and 1% significance levels, respectively.

The estimated coefficients of $SCH_{it} \ln(A^{max} / A_i)_{t-1}$ are economically and statistically significant for the overall sample. This supports the hypothesis put forward by Nelson and Phelps (1966) and the empirical findings of Benhabib and Spiegel (1994) and Kneller and Stevens (2006) that an educated labor force increases the absorptive capacity of countries that are behind the technology frontier. However, it is not significant for the sub-samples. Looking at Figure 3 these results are not surprising. The figure shows a clear positive relationship for the overall sample; however, looking closer at the sub-samples the relationship becomes blurred. The low-income countries tend to cluster in the north-east corner of the graph and the developed countries tend to cluster in the south-west corner. This suggests that the results for the sub-samples are influenced by a small sample bias.

Finally, considering the effects of the control variables, foreign direct investment as a proportion of GDP, trade openness and inflation are all significant and carry the right signs in the full sample regressions; however, they are rarely significant in the two separate samples, which may again be a small sample issue. Almost all of the estimated coefficients of these control variables are insignificant for both country groups. Moreover, we do not find any significant effects of financial development and distance from the equator.

Table 3: TFP growth equations (unrestricted and restricted estimates of Eq. (4) using *R/Y*)

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.008** (2.17)	0.009* (1.77)	0.01 (1.44)	0.01** (2.24)	0.01* (1.75)	0.02** (2.32)	0.008 (0.92)	0.001 (0.33)	-0.005 (-0.82)
$\ln(A^{max}/A_i)_{t-1}$	0.01*** (3.45)	0.002 (0.41)	0.02* (1.82)	0.03*** (2.76)	0.03*** (2.76)	0.02** (2.13)	0.02*** (2.77)	0.02** (2.38)	0.02** (2.08)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.008 (-1.15)		-0.01 (-1.02)	-0.006 (-1.05)		-0.02 (-1.22)	-0.005 (-0.37)		0.01 (1.16)
$\ln SCH_{it}$	0.01** (2.16)	-0.004 (-0.50)	0.01 (0.56)	-0.01 (-1.49)	-0.008 (-0.76)	-0.02 (-1.61)	0.01* (1.82)	0.02 (1.58)	0.02* (1.84)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.003** (2.10)	-0.001 (-0.36)		-0.002 (-1.16)	0.003 (0.76)		-0.002 (-0.78)	-0.003 (-1.15)
$\Delta \ln TO_{it}$	0.02** (2.30)	0.02** (2.42)	0.04*** (3.44)	-0.01 (-0.65)	-0.01 (-0.73)	-0.001 (-0.03)	0.01 (0.99)	0.02 (1.49)	0.02* (1.70)
ΔFY_{it}	0.17** (2.52)	0.15*** (2.67)	0.21*** (3.06)	0.18 (1.21)	0.17 (1.26)	0.24* (1.92)	0.03 (0.30)	-0.004 (-0.04)	0.001 (0.01)
ΔINF_{it}	-0.004 (-0.48)	-0.005 (-0.55)	-0.01 (-0.82)	0.04 (1.38)	0.04 (1.24)	0.05 (1.60)	0.0002 (0.02)	-0.003 (-0.30)	-0.005 (-0.51)
$\Delta \ln FD_{it}$	-0.002 (-0.52)	-0.001 (-0.19)	-0.005 (-0.54)	-0.01 (-1.43)	-0.008 (-1.45)	-0.01 (-1.16)	0.002 (0.40)	0.001 (0.19)	0.0007 (0.12)
DE_{it}	0.009 (0.87)	0.009 (0.65)	0.02 (0.62)	0.006 (0.48)	0.008 (0.58)	0.006 (0.57)	0.002 (0.10)	0.008 (0.37)	0.01 (0.56)
Hansen (*p*-value)	0.75	0.65	0.57	0.99	0.80	0.96	0.76	0.90	0.99
Difference-in-Hansen (*p*-value)	0.80	0.57	0.63	0.99	0.85	0.97	0.83	0.99	0.99
AR(2) (*p*-value)	0.64	0.95	0.74	0.13	0.17	0.44	0.66	0.73	0.70

Notes: See notes to Table 2. (*X/Q*) is measured as the share of R&D expenditure in GDP (*R/Y*).

Tables 3 and 4 report the results of estimating Eq. (4) where research intensity is measured as the share of R&D expenditure in total GDP (*R/Y*) and the number of patent applications divided by the labor force (*P/L*), respectively. The results are quite similar to those in Table 2; however, the interaction between research intensity and the distance to the frontier are statistically insignificant and research intensity is slightly less significant, which may reflect that (*R/Y*) and (*P/L*) are less suitable measures of research intensity than (*N/L*). The problem associated with (*R/Y*) is that R&D is deflated by the GDP deflator only because of the erratic behavior of wages for some countries as noted in footnote 1. As wages are increasing more than the GDP deflator due to productivity advances over time, increases in real R&D will be exaggerated. The problem associated with (*P/L*) is that patents are outcomes of innovations and not imitations and, as such, miss out a significant part of R&D activity. Despite these measurement problems the results give support for the findings above that R&D intensity, distance to the frontier and its interaction with educational attainment are important for growth.

Table 4: TFP growth equation (unrestricted and restricted estimates of Eq. (4) using *P/L*)

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.008*** (2.93)	0.007* (1.70)	0.01** (2.17)	0.01** (2.06)	0.01** (2.65)	0.01*** (2.97)	0.01** (2.20)	0.01* (1.79)	0.009* (1.85)
$\ln(A^{max}/A_i)_{t-1}$	0.02*** (3.26)	0.004 (0.22)	0.02*** (3.89)	0.03** (2.12)	0.05* (1.72)	0.05* (1.85)	0.05*** (3.53)	0.001 (0.05)	0.008 (0.55)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.005 (-0.34)		-0.01 (-0.29)	-0.03 (-1.11)		-0.03 (-0.81)	-0.28 (-1.05)		-0.03 (-0.34)
$\ln SCH_{it}$	-0.005 (-1.14)	-0.04 (-1.44)	-0.01 (-1.08)	-0.02 (-1.58)	-0.01 (-0.97)	-0.01 (-0.88)	0.01 (0.44)	-0.04 (-1.62)	-0.03 (-1.51)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.009* (1.71)	0.001 (0.45)		-0.006 (-1.59)	-0.003 (-0.55)		0.01** (2.12)	0.008** (2.14)
$\Delta \ln TO_{it}$	0.02** (2.13)	0.05*** (3.14)	0.02* (1.95)	-0.01 (-0.70)	-0.004 (-0.18)	-0.02 (-1.01)	0.02 (1.06)	0.02 (1.31)	0.03*** (2.93)
ΔFY_{it}	0.19** (2.34)	0.26** (2.18)	0.18** (2.13)	0.15 (0.96)	0.24 (1.58)	0.19* (1.79)	0.13 (0.69)	0.27** (2.07)	0.17 (1.18)
ΔINF_{it}	-0.01** (-2.27)	-0.01* (-1.75)	-0.01** (-2.19)	0.03 (0.86)	0.002 (0.03)	0.04 (0.95)	-0.02 (-1.51)	-0.01* (-1.83)	-0.01* (-1.73)
$\Delta \ln FD_{it}$	-0.002 (-0.57)	-0.002 (-0.29)	-0.003 (-0.59)	-0.01 (-1.40)	-0.01 (-1.56)	-0.01 (-1.60)	-0.009 (-0.94)	-0.005 (-0.82)	0.003 (0.48)
DE_{it}	0.01 (1.58)	0.05 (1.43)	0.01 (0.90)	0.01 (1.11)	-0.001 (-0.04)	0.01 (0.50)	-0.007 (-0.05)	0.05 (0.92)	0.02 (0.72)
Hansen (p-value)	0.52	0.37	0.93	0.99	0.99	0.99	0.36	0.81	0.99
Difference-in-Hansen (*p*-value)	0.81	0.64	0.99	0.99	0.99	0.99	0.62	0.98	0.99
AR(2) (p-value)	0.83	0.85	0.97	0.14	0.30	0.12	0.40	0.34	0.32

Notes: See notes to Table 2. (*X/Q*) is measured as the number of patent applications filed by domestic residents relative to the total labor force (*P/L*).

5. Robustness Checks

A series of sensitivity checks are undertaken in this section to ensure the robustness of the results reported in the previous section to an alternative growth framework, alternative data sets, alternative measurement of key variables, measurement in 10 and 34-year intervals, different functional forms and other specification issues. The estimation results are not reported here to conserve space but they are provided and discussed in detail in the appendix. Since our principal results are insensitive to the way research intensity is measured, it is computed as the ratio of R&D scientists and engineers to the labor force (N/L). This allows a direct comparison with the key results reported in Table 2. Unless otherwise stated, the estimates are based on the system GMM estimator, the same set of instruments is used and the variables are measured in 5-year intervals. Moreover, the regression approach suggested by Basu *et al.* (2006) is used to ensure that all business cycle influences are filtered out.

5.1 Alternative growth framework. The estimates in the previous section are based on the Schumpeterian framework and, as such, do not allow for the possibility that R&D has only temporary growth effects following the predictions of the semi-endogenous growth theory of Jones (1995a, b) (see, e.g., Madsen, 2008b for discussion). To cater for this, the growth rate of R&D labor ($\Delta \ln X_{it}$), the growth rate of educational attainment ($\Delta \ln SCH_{it}$) and their interaction with distance to the frontier [$(\Delta \ln X_{it}) \ln(A^{\max} / A_i)_{t-1}$ and $(\Delta \ln SCH_{it}) \ln(A^{\max} / A_i)_{t-1}$] are included as additional regressors in Eq. (4). As reported in Table A1, contrary to the predictions of the semi-endogenous growth models, in hardly any cases are any of these variables significant. Furthermore, the parameter estimates of the variables considered in Eq. (4) are largely unaffected by the inclusion of these additional regressors. Hence, we can conclude that the Schumpeterian growth model is the appropriate framework for the analysis in this paper.

5.2 Alternative measures of capital stock, educational attainment, and technology gap. The initial level of capital stock has thus far been computed as $I_0 /(\delta + g)$. However, I_0 may be influenced by business cycles and transitional dynamics. To address this concern, the structural initial capital stock is estimated as a linear transformation of the average investment ratio over the period 1970-2004, as detailed in the appendix. Moreover, our analysis so far uses the average years of schooling of the population aged 25 and over provided by Barro and Lee (2001) as the measure of educational attainment. Since educational attainment plays an important role in this study and is subject to large measurement errors, we also run the regressions using the dataset of educational attainment of the labor force compiled by Cohen and Soto (2007). They argue that their dataset is subject to fewer measurement errors than that of Barro and Lee (2001). Finally, $A^{\max}$ has thus far been measured by the TFP or labor productivity for the U.S. However, a closer examination of the data reveals that the TFP was indeed higher for Ireland than the U.S. over the period 2001-2004.

Moreover, labor productivity in Switzerland was higher than that of the US from 1970-1975 and 1979-1984. Therefore, we provide a sensitivity check in which the technological leader is the country with the highest TFP or labor productivity at any point in time. None of the estimation results obtained in Table 2 are significantly affected by these alternative measures of TFP, reinforcing the robustness of these results (see Tables A2-A4).

5.3 Long estimation intervals. In our empirical estimation, we have used data that are averaged or differenced over 5 year periods to filter out business cycle influences and to mitigate the effects of transitional dynamics. However, the longer is the period over which differences or the averages are taken, the less the estimates are influenced by business cycles and transitional dynamics. Thus, estimates in 10-year intervals and for the full sample period (1970 to 2004) are undertaken here. This comes at the cost of an efficiency loss due to a smaller number of available observations. The regression results (see Tables A5 and A6) are largely in line with those obtained in Table 2 except that the coefficients of R&D-based absorptive capacity for the full sample period now become insignificant for developing countries, probably because the number of observations is now very low for these countries.

5.4 The roles of trade openness and foreign direct investment. Keller (2004) argues that openness to international trade and FDI may work effectively as channels of international technology transfer. Countries that are more open to international trade and FDI are better equipped to take advantage of the technology that is developed in the frontier countries and, therefore, catch up quicker to the technology frontier. Allowing for these effects on growth yields the following specification (see the appendix for the derivation):[4]

$$\Delta \ln A_{it} = a_i + b' F_{it} + c \ln\left(\frac{A_{t-1}^{\max}}{A_{i,t-1}}\right) + d' F_{it} \ln\left(\frac{A_{t-1}^{\max}}{A_{i,t-1}}\right) + \upsilon_{it} \tag{6}$$

where F is a vector of variables consisting of R&D, educational attainment, trade openness and FDI divided by nominal GDP, and υ_{it} is the stochastic error term. Here, $b' F_{it}$ captures the direct effects and $d' F_{it} \ln(A_{t-1}^{\max} / A_{i,t-1})$ captures the indirect effects of *F* on TFP growth.

[4] The framework of Griffith *et al.* (2000) can also be used to derive Eq. (6). In their model, the equilibrium R&D is at the point at which the individual is indifferent between intermediate production and R&D. Eq. (6) can be derived by allowing the potential of imitations through the channels of *FY* and *TO* to be functions of distance to the frontier.

The results of estimating this equation give little support for the hypothesis that trade openness and FDI increase the pace at which countries gravitate to the technological frontier (see Table A7). The estimated coefficients of the interaction between distance to the frontier and FDI or trade openness are barely significant or not significant at all. The estimated coefficients of other variables are qualitatively very similar to the base case, suggesting that the benefits from technological backwardness can best be exploited by developing countries through enhancing domestic R&D intensity and investment in education.

5.5 Other robustness checks. Finally, the robustness of the results to an alternative estimator (see Table A8), to double log form of the absorptive capacity (see Table A9) and to alternative control variables and instruments (see Tables A10 and A11) is examined. First, the least squares dummy variable (LSDV) estimator for dynamic panel data models (a bias-corrected estimator for the fixed-effects dynamic panel data model that uses dummy variables) overcomes the finite sample bias that the GMM estimator is subject to (see, e.g., Kiviet, 1999; Bruno, 2005). Second, instead of measuring absorptive capacity by the terms $(X/Q)_{it}\ln(A^{\max}/A_i)_{t-1}$ and $SCH_{it}\ln(A^{\max}/A_i)_{t-1}$, they were expressed in a double-log form as $\ln(X/Q)_{it}\ln(A^{\max}/A_i)_{t-1}$ and $\ln SCH_{it}\ln(A^{\max}/A_i)_{t-1}$. Third, we consider changes in the GDP deflator, the ratio of *M*3 to GDP and landlockness as alternative measures of inflation, financial development and geographical location, respectively.

Finally, we consider an alternative set of external instruments. *Effectiveness of legislature* is found to be highly correlated with other widely used institutional variables such as *civil liberties* and *political rights*, *polity*, *ICRG* composite index, *law and order* and *corruption* (the coefficient of correlations is greater than 0.70 for all the variables).[5] Therefore, we check the consistency of our results by replacing *effective legislature* with these institutional variables as alternative external instruments for R&D. Since the results are highly consistent irrespective of the indicators considered, we only report results based on *civil liberties* in the appendix. In all cases, the results are, by and large, very consistent with those reported in Table 2, thus reinforcing the evidence that the results in the previous section are fairly robust.

[5] Data on *political rights* and *civil liberties* are downloaded from http://www.freedomhouse.org/. Data before 1973 are extrapolated. Data on *polity* are available for the full sample period and are gathered from the Center for Global Policy (http://globalpolicy.gmu.edu/). The *ICRG* composite index, *law and order*, and *corruption* data obtained from the Political Risk Services (PRS) Group and are only available from 1984.

6. Concluding Remarks

The role of R&D in promoting TFP growth has become increasingly prominent in the empirical growth literature. However, almost all empirical research so far has focused on OECD countries where evidence of the positive effects of domestic and foreign R&D on growth has been well-documented. Given that developing countries are latecomers, they may well have greater potential for catching up to the technology leader through investment in R&D and education that facilitates the transfer of foreign technology. This hypothesis is tested in this paper using data for 23 OECD countries and 32 developing countries over the period 1970-2004.

The results show that R&D intensity, its interaction with distance to the frontier, educational attainment-based absorptive capacity and technology gap influence TFP growth positively. However, the direct effect of educational attainment is found to have little effect on TFP growth. While the growth effects of research intensity and distance to the frontier generally apply to all country groups, the growth-enhancing effects of educational attainment-based absorptive capacity are limited to the full sample only. Furthermore, R&D intensity-based absorptive capacity is found to have growth effects only in the developing country sample.

These results provide several important insights. First, educational attainment facilitates convergence to the technological frontier. Second, while the growth effects of R&D are through innovation in OECD countries, the growth effects of R&D arise mainly through imitation in the developing countries. Third, being far behind the technological frontier does not automatically generate growth. A developing country needs to invest in R&D to be able to take advantage of the technology that is developed at the frontier.

The findings of this study provide some insights into future growth prospects for both developed and developing countries and policy lessons for the formulation of development strategy. First, the significance of R&D intensity in explaining TFP growth in OECD countries implies that growth will continue at the present rates for countries at or close to the technology frontier, provided that R&D is kept to a fixed proportion of the number of product lines. Second, developing countries that invest in R&D will continue to grow due to the positive growth effects of the interaction between distance to the frontier and research intensity. When research intensive developing countries eventually move closer to the frontier, research intensity will take over as the main engine of growth as the economies evolve from being just imitators to being both imitators and innovators.

Appendix: Further Robustness Checks

In this appendix we perform a series of sensitivity checks to ensure robustness of the results reported in the main text. While performing these checks, our results are not sensitive to the way research intensity is measured. We have therefore reported only the results for which research intensity is measured using the ratio of R&D scientists and engineers to the labor force (N/L). This allows a direct comparison with the key results reported in Table 2 in the main text. Unless otherwise stated, we continue to use a system GMM estimator with data in 5-year intervals and the same set of internal and external instruments to derive the estimates. Moreover, the regression approach suggested by Basu *et al.* (2006) is used to ensure that all business cycle influences are filtered out.

(1) Testing the implications of semi-endogenous theory for growth

The functional relationship between productivity growth and R&D is an active research topic in the economic growth literature. Following Jones' (1995) critique of the predictions of the first-generation endogenous growth models of Romer (1990) and Aghion and Howitt (1992), a positive relationship between the *level* of R&D and productivity growth is generally no longer accepted as an empirical regularity in the growth literature. Instead, the second-generation models such as Schumpeterian and semi-endogenous growth theory have gradually become the dominant paradigm in growth.

These second-generation growth models have recently been tested by Ha and Howitt (2007), Madsen (2008) and Madsen *et al.* (2009), and they consistently find support for the Schumpeterian growth model and no support for semi-endogenous growth models in explaining growth in the U.S., OCED, and India, respectively. To compare our results with this strand of literature and check whether the use of a semi-endogenous growth framework can also be supported by the data, we include the growth rate of R&D workers ($\Delta \ln X_{it}$), the growth rate of educational attainment ($\Delta \ln SCH_{it}$) and their interaction with distance to the frontier [$(\Delta \ln X_{it})\ln(A^{\max}/A_i)_{t-1}$ and $(\Delta \ln SCH_{it})\ln(A^{\max}/A_i)_{t-1}$] in the regressions. Against the predictions of the semi-endogenous growth models, the results reported in Table A1 indicate that in hardly any cases are the coefficients of these variables significantly positive. Hence, we can conclude that the Schumpeterian model is the appropriate framework in our context.

(2) Alternative measure of capital stock

In this paper, the initial capital stock is estimated using the Solow model steady-state value of $I_0/(\delta + g)$, where I_0 is initial real investment, δ is the rate of depreciation (assumed to be 5%), and g is the geometric average annual growth rate in real investment over the period 1970-2004. While this is a standard practice in the literature, the procedure for selecting the initial value of capital may appear to be somewhat arbitrary and it may be subject to business cycle movements and transitional dynamics. To address this concern, the structural initial capital stock is estimated as a linear transformation of the average investment ratio. Assuming that the economies on average were in their steady states during the period 1970-2004 we can undertake the following transformation to find the steady-state investment in 1970. First, we compute $\hat{\alpha}_i$ for each individual country:

$$\left(\frac{I}{Y}\right)_{i,1970} = \hat{\alpha}_i \left(\frac{I}{Y}\right)_{i,1970-2004},$$

(A1)

where $(I/Y)_{1970}$ is the investment ratio in 1970 and $(I/Y)_{1970\text{-}2004}$ is the average investment ratio in the period 1970-2004 and $\hat{\alpha}_i$ is a constant for country *i*. Here, $\hat{\alpha}_i$ may differ from one because country *i* was outside its balanced growth path in 1970 or because it was outside an average cyclical position. Once $\hat{\alpha}_i$ is calculated the steady-state investment can be readily computed from $I^{SS}_{i,1970} = \hat{\alpha}_i Y_{i,1970}$ and the initial steady-state capital stock is computed from the following expression:

$$K^{SS}_{i,1970} = \frac{I^{SS}_{i,1970}}{\delta + g_{i,1970-2004}},$$

(A2)

where $g_{i,1970-2004}$ is the average annual growth rate in investment for country *i*.

The estimates reported in Table A2 show that the main results are not sensitive to the choice of the initial value of real investment. These findings reinforce the results from the estimates in very long first differences (see Section A5 below) that our estimates in the main body of the text are not influenced significantly by transitional dynamics.

(3) Alternative human capital data

Human capital has been measured using data on the average years of schooling of the population aged 25 and over provided by Barro and Lee (2001). The dataset of Barro and Lee (2001), however, has been subject to much criticism in recent years (see, e.g., de la Fuente and Doménech, 2006 and Cohen and Soto (2007). Furthermore, the estimated coefficients of educational attainment were in most cases insignificant. To address these concerns we use the human capital dataset compiled by Cohen and Soto (2007). They argue that this refined dataset is subject to fewer measurement errors than the Barro-Lee data set and produces more superior regression results. The use of the Cohen-Soto dataset, however, does not lead to any significant improvement in our estimates. As shown in Table A3, the regression results are quite similar to those obtained earlier, suggesting that the quality of human capital data may not be a concern in our context.

(4) Alternative measure of distance to the frontier

The distance to the frontier (A^{max}/A) is measured by the TFP gap or labor productivity gap between the U.S. and country i in the main text. We have, therefore, implicitly assumed that the technological leader has been the U.S. over the entire sample period. A closer examination of the data reveals that the TFP was indeed higher for Ireland than the U.S. over the period 2001-2004. Ireland has enjoyed very high TFP growth rates over the past two decades because of its high investment in R&D and its ability to attract high technology multinational firms. Moreover, the labor productivity of Switzerland was higher than that of the US from 1970-1975 and 1979-1984. We provide a sensitivity check using an alternative measure of distance to the frontier where the technological leader is the country with the highest TFP at any point in time. The results, however, are unlikely to change significantly given that this affects only a small portion of the sample period. Our results reported in Table A4 confirm this conjecture. The estimates are almost qualitatively identical with those reported in the main text, suggesting the treatment of the U.S. as the technological leader throughout the sample period is a reasonable assumption.

(5) Long estimation intervals

In our empirical estimation, we have used data averaged or differenced over 5 years to filter out the influence of business cycles on the data. However, since there is no guarantee that all business cycle fluctuations are filtered out by the 5-year differences or averages, we also estimate in 10-year intervals as well as for the full sample period (1970 to 2004). Another advantage associated with the use of 10 year differences or one observation per country is that a long transitional period is required to achieve steady-state equilibrium in the Schumpeterian growth framework. The regression results (see Tables A5 and A6) are largely in line with those obtained in Table 2 except that the coefficients of R&D-based absorptive capacity for the full sample period now become insignificant for developing countries, probably because the number of observations is now very low for these countries.

(6) The roles of trade openness and foreign direct investment

Keller (2004) argues that openness to international trade and FDI may work effectively as channels of international technology transfer. This is because countries that are more open to international trade and foreign direct investment are better equipped to take advantage of the technology that is developed at the frontier countries. Thus, international trade and FDI both affect the speed at which the technological gap is closed. The implications of the interaction between international trade or foreign direct investment (FDI) and distance to the frontier for TFP growth can be derived using the following simple approach.

According to Bernard and Jones (1996a, b), TFP growth is a function of technological catch-up given that countries which are relatively backward can grow faster by utilizing technologies developed in the leading country. Thus, we can assume that TFP growth depends on:

$$\Delta \ln A_{it} = \alpha_i + \beta_i \ln\left(\frac{A_{t-1}^{\max}}{A_{i,t-1}}\right) + \gamma' X_{it} + \varepsilon_{it}, \quad \alpha_i, \beta_i \geq 0$$

(A3)

where α_i is the rate of innovation growth, β_i parameterizes the rate of technological catch up, $A_{t-1}^{\max} / A_{i,t-1}$ is a variable measuring the technology gap between the frontier and the domestic economy (or distance to the frontier), X is a vector of control variables, and distance from the equator, as discussed in section A1), and ε_{it} is the stochastic error term.

A number of studies have emphasized the importance of R&D, human capital, international trade and FDI in facilitating innovation and technology transfer (see, e.g., Griffith *et al.*, 2004; Keller, 2004). We therefore follow the approach of Griffith *et al.* (2000) and Cameron *et al.* (2005) by allowing both innovation (α_i) and the rate of technology transfer (β_i) to be functions of R&D, human capital, international trade and foreign direct investment, as follows:

$$\alpha_i = a_i + b' F_{it} \,, \quad \beta_i = c + d' F_{it}$$

(A4)

where F is a vector including R&D, human capital, trade openness and FDI. Thus, Eq. (A3) becomes:

$$\Delta \ln A_{it} = a_i + b' F_{it} + c \ln \left(\frac{A_{t-1}^{\max}}{A_{i,t-1}} \right) + d' F_{it} \ln \left(\frac{A_{t-1}^{\max}}{A_{i,t-1}} \right) + \gamma' X_{it} + \varepsilon_{it}$$

(A5)

where $b' F_{it}$ captures the direct effect on TFP growth and $d' F_{it} \ln(A_{t-1}^{\max} / A_{i,t-1})$ captures the indirect effects on TFP growth.

The results of estimating this equation give little support for the hypothesis that trade openness and FDI increase the pace at which countries gravitate to the technological frontier (see Table A7). The estimated coefficients of the interaction between distance to the frontier and FDI or trade openness are barely significant or not significant at all. The estimated coefficients of other variables are qualitatively very similar to the base case, suggesting that the benefits from technological backwardness can best be exploited through enhancing domestic R&D intensity or investment in education.

(7) Alternative estimator

Although the system GMM estimator used throughout the paper is efficient in exploiting the time series variations of data, accounting for unobserved country specific effects, and controlling for endogeneity bias, it is well known that this estimator may be subject to finite sample bias (see, e.g., Windmeijer, 2005). To provide a robustness check to the estimates, we also perform the least squares dummy variable (LSDV) estimator for dynamic panel data models (a bias-corrected estimator for the fixed-effects dynamic panel data model that uses dummy variables) to overcome the finite sample bias that the GMM estimator is subject to (see, e.g., Kiviet, 1999; Bruno, 2005). These considerations, however, do not distort our findings regarding the effects of technology transfer, R&D intensity and human capital on productivity growth. As shown in Table A8, the estimates are broadly in line with those reported in Table 2 in the main text.

(8) Measuring absorptive capacity in a double-log form

While our measures of absorptive capacity for both research intensity and human capital [$(X/Q)_{it}\ln(A^{\max}/A_i)_{t-1}$ and $SCH_{it}\ln(A^{\max}/A_i)_{t-1}$] are consistent with the theoretical derivations of Nelson and Phelps (1966), Howitt (2000) and Griffith *et al.* (2003), these variables can also be expressed in a double-log form [$\ln(X/Q)_{it}\ln(A^{\max}/A_i)_{t-1}$ and $\ln SCH_{it}\ln(A^{\max}/A_i)_{t-1}$]. The estimates reported in Table A9 show that the effect of R&D-based absorptive capacity is slightly weaker in the developing country sample, but other estimates are broadly in line with the earlier results.

(9) Alternative control variables and instruments

Finally, we consider changes in the GDP deflator, the ratio of *M*3 to GDP and landlockness as alternative measures of inflation, financial development and geographical location, respectively. We also consider an alternative set of external instruments. *Effectiveness of legislature* is found to be highly correlated with other widely used institutional variables such as *civil liberties* and *political right*, *polity*, *ICRG* composite index, *law and order* and *corruption* (the coefficient of correlations is greater than 0.7 for all the variables). Therefore, we check the consistency of our results by replacing *effective legislature* with these institutional variables as alternative external instruments for R&D. Since the results are highly consistent irrespective of the indicators considered, we report only results based on *civil liberties* in the Table A11. In all cases, the results are by and large very consistent with those reported in Table 2. Moreover, our key findings are not sensitive to the use of alternative control variables (see Table A10), thus reinforcing the evidence that the results in the previous section are fairly robust.

Table A1: TFP growth estimates – incorporating the implications of semi-endogenous theory

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln(X/Q)_{it}$	0.01^{***} (3.02)	0.01^{***} (2.90)	0.01^{***} (2.96)	0.02^{*} (1.79)	0.01^{**} (2.40)	0.01^{***} (3.13)	-0.003 (-0.71)	0.009^{**} (2.17)	-0.009 (-1.48)
$\Delta \ln X_{it}$	0.02 (1.59)	-0.008 (-1.29)	0.02 (1.55)	-0.004 (-0.26)	0.01 (1.14)	0.02 (1.33)	0.01 (0.83)	-0.01 (-1.36)	0.01 (0.88)
$\ln(A^{max}/A_i)_{t-1}$	0.02^{***} (4.41)	0.01^{*} (1.95)	0.01^{*} (1.69)	0.02^{*} (1.79)	0.02 (0.45)	0.01 (0.03)	0.01^{**} (2.71)	0.01^{*} (1.82)	0.01^{*} (1.76)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.001 (0.81)		-0.002 (-0.80)	0.001 (0.37)		-0.0002 (-0.09)	0.02^{*} (1.84)		0.02^{*} (1.96)
$\Delta \ln X_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.02 (-1.59)		-0.02 (-1.57)	0.02 (0.68)		-0.03 (-1.19)	-0.01 (-0.88)		-0.01 (-0.81)
$\ln SCH_{it}$	0.009^{**} (2.36)	-0.004 (-0.60)	-0.008 (-0.93)	-0.01 (-0.95)	-0.002 (-0.16)	-0.01 (-1.38)	0.01^{**} (2.52)	0.001 (0.11)	0.02^{*} (1.96)
$\Delta \ln SCH_{it}$	-0.009 (-0.51)	-0.02 (-0.74)	-0.03 (-1.29)	0.03 (0.79)	-0.08 (-1.40)	-0.11^{***} (-2.94)	-0.02 (-1.02)	-0.01 (-0.36)	-0.03 (-0.70)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.002^{**} (2.10)	0.003^{**} (2.11)		-0.001 (-0.15)	0.0006 (0.26)		0.002 (0.80)	-0.001 (-0.59)
$\Delta \ln SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.006 (0.42)	0.02 (1.33)		0.22 (1.13)	0.37 (1.46)		-0.002 (-0.11)	0.004 (0.15)
Hansen (*p*-value)	0.97	0.69	0.96	0.99	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*-value)	0.99	0.92	0.99	0.99	0.98	0.99	0.99	0.99	0.99
AR(2) (*p*-value)	0.84	0.77	0.84	0.28	0.66	0.12	0.94	0.93	0.79

Notes: the regressions include trade openness, FDI over GDP, inflation, financial development and distance from the equator as control variables. Their coefficients are not reported here to conserve space. See also notes to Table 2.

Table A2: TFP growth estimates based on alternative measure of capital stock

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln(X/Q)_{it}$	0.05^{***} (2.70)	0.08^{**} (2.35)	0.06^{**} (2.64)	0.07^{*} (1.82)	0.07^{**} (2.11)	0.07^{*} (1.97)	-0.02 (-0.75)	0.04^{*} (1.76)	-0.03 (-1.04)
$\ln(A^{max}/A_i)_{t-1}$	0.11^{***} (4.11)	0.07^{*} (1.87)	0.05^{*} (1.92)	0.20^{***} (3.85)	0.24^{**} (2.11)	0.21^{**} (2.66)	0.04^{*} (1.76)	0.07^{*} (1.89)	0.05 (1.49)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.004 (0.41)		-0.009 (-0.63)	-0.01 (-0.85)		0.005 (0.39)	0.13^{**} (2.22)		0.13^{**} (2.28)
$\ln SCH_{it}$	0.04^{*} (1.87)	-0.05 (-1.04)	-0.04 (-0.74)	-0.05 (-0.82)	0.06 (0.80)	0.03 (0.40)	0.06^{**} (2.52)	0.01 (0.18)	0.08 (1.37)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.02^{**} (2.23)	0.02^{*} (1.88)		-0.007 (-0.30)	-0.02 (-1.12)		0.007 (0.68)	-0.001 (-0.15)
Hansen (*p*-value)	0.49	0.46	0.66	0.99	0.97	0.99	0.99	0.96	0.99
Diff-in-Hansen (*p*-value)	0.44	0.65	0.79	0.99	0.99	0.99	0.93	0.92	0.99
AR(2) (*p*-value)	0.75	0.72	0.95	0.14	0.37	0.49	0.95	0.54	0.79

Notes: see notes to Table A1.

Table A3: TFP growth estimates based on the Cohen-Soto human capital data

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.01^{***} (2.67)	0.01^{*} (1.88)	0.01^{***} (2.72)	0.02^{**} (2.08)	0.02^{*} (1.94)	0.02^{**} (2.10)	-0.004 (-0.75)	0.005 (1.03)	-0.006 (-1.15)
$\ln(A^{max}/A_i)_{t-1}$	0.02^{***} (4.06)	0.01^{**} (2.01)	0.01^{*} (1.95)	0.02^{*} (1.74)	0.05^{**} (2.69)	0.04 (1.51)	0.01^{*} (1.83)	0.01^{***} (3.21)	0.01 (1.39)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.001 (0.66)		-0.002 (-0.70)	-0.003 (-0.96)		0.0002 (0.01)	0.02^{*} (1.80)		0.02^{**} (2.12)
$\ln SCH_{it}$	0.008^{***} (2.79)	-0.004 (-0.40)	-0.004 (-0.47)	-0.04 (-1.44)	-0.008 (-0.22)	-0.02 (-0.83)	0.01^{***} (3.38)	0.005 (0.73)	0.01^{*} (1.96)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.002^{*} (1.82)	0.002 (1.58)		-0.005 (-1.28)	-0.004 (-0.81)		0.001 (0.90)	0.0001 (0.13)
Hansen (*p*-value)	0.59	0.29	0.80	0.99	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*-value)	0.97	0.56	0.99	0.99	0.99	0.99	0.90	0.99	0.99
AR(2) (*p*-value)	0.61	0.58	0.88	0.19	0.67	0.28	0.78	0.53	0.73

Notes: see notes to Table A1.

Table A4: TFP growth estimates based on alternative measure of distance to the frontier

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.01^{***} (2.94)	0.01^{**} (2.47)	0.01^{***} (2.71)	0.02^{**} (2.20)	0.02^{**} (2.16)	0.01^{**} (2.04)	-0.002 (-0.43)	0.01^{*} (1.88)	-0.004 (-0.70)
$\ln(A^{max}/A_i)_{t-1}$	0.02^{***} (4.55)	0.01^{*} (1.92)	0.01^{*} (1.86)	0.03^{***} (2.79)	0.05^{**} (2.01)	0.04^{*} (1.80)	0.01^{**} (2.48)	0.01^{**} (2.05)	0.01^{*} (1.91)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.0001 (0.08)		-0.002 (-0.73)	-0.004 (-1.04)		-0.002 (-0.42)	0.02^{**} (2.04)		0.02^{**} (2.02)
$\ln SCH_{it}$	0.008^{**} (2.12)	-0.007 (-0.89)	-0.009 (-0.94)	-0.02 (-1.58)	-0.007 (-0.31)	-0.01 (-0.84)	0.01^{**} (2.56)	0.001 (0.10)	0.01 (1.46)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.003^{**} (2.40)	0.003^{**} (2.02)		-0.004 (-0.81)	-0.003 (-0.61)		0.002 (0.89)	-0.0002 (-0.12)
Hansen (*p*-value)	0.81	0.99	0.41	0.99	0.99	0.99	0.99	0.99	0.99
Diff-in-Hansen (*p*-value)	0.99	0.43	0.24	0.97	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-value)	0.75	0.72	0.61	0.12	0.37	0.11	0.66	0.51	0.51

Notes: see notes to Table A1.

Table A5: TFP estimates using 10-year intervals data

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln(X/Q)_{it}$	0.004	0.01*	0.01*	0.01**	0.01***	0.01**	-0.003	0.01*	-0.01
	(1.52)	(1.90)	(1.84)	(2.03)	(3.48)	(2.24)	(-0.80)	(1.67)	(-0.76)
$\ln(A^{max}/A_i)_{t-1}$	0.01***	0.01	0.01**	0.02***	0.03***	0.02**	0.01***	0.03***	0.04***
	(3.97)	(1.21)	(2.33)	(4.48)	(3.34)	(2.34)	(2.80)	(3.90)	(3.01)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.001		-0.006	-0.001		-0.002	0.02**		0.05**
	(-0.25)		(-1.60)	(-0.45)		(-1.09)	(2.16)		(2.03)
$\ln SCH_{it}$	0.007*	-0.01	-0.004	-0.01	-0.01	-0.001	0.01**	0.01	0.02
	(1.76)	(-0.92)	(-0.45)	(-1.52)	(-1.12)	(-1.60)	(2.25)	(1.15)	(1.48)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.003*	0.003*		-0.001	0.001		-0.003	-0.004
		(1.72)	(1.78)		(-0.71)	(0.55)		(-0.99)	(-1.35)
Hansen (*p*-value)	0.18	0.29	0.11	0.30	0.15	0.31	0.31	0.39	0.22
Diff-in-Hansen (*p*-value)	0.19	0.15	0.15	0.26	0.14	0.64	0.32	0.27	0.79

Notes: AR(2) is not available since the estimation here involves a much shorter time horizon. See also notes to Table A1.

Table A6: TFP growth estimates based on the pure cross-sectional estimator

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln(X/Q)_i$	0.003**	0.004***	0.005***	-0.002	0.001	0.006	0.002	0.005**	0.003
	(2.07)	(3.70)	(3.52)	(-0.43)	(0.46)	(1.05)	(0.40)	(2.33)	(1.00)
$\ln(A^{max}/A_i)_{1970}$	0.009***	0.001	0.0001	0.004	-0.007	-0.009	0.008**	0.003	0.002
	(3.92)	(0.20)	(0.17)	(0.76)	(-0.77)	(-0.95)	(2.26)	(0.66)	(0.41)
$(X/Q)_i \times \ln(A^{max}/A_i)_{1970}$	0.001		-0.001	0.001		-0.002	0.009		0.006
	(1.16)		(-1.10)	(1.28)		(-0.96)	(0.93)		(0.87)
$\ln SCH_i$	0.007***	-0.004	-0.005	0.0003	-0.01	-0.02	0.009**	-0.002	-0.001
	(2.73)	(-0.83)	(-1.00)	(0.001)	(-1.15)	(-1.48)	(2.44)	(-0.26)	(-0.02)
$SCH_i \times \ln(A^{max}/A_i)_{1970}$		0.002***	0.003***		0.002*	0.004*		0.002	0.002
		(3.11)	(3.20)		(1.95)	(1.97)		(1.53)	(1.50)
R-Squared	0.54	0.61	0.62	0.64	0.71	0.73	0.58	0.61	0.62
Observation	55	55	55	23	23	23	32	32	32

Notes: see notes to Table A1.

Table A7: TFP growth estimates – incorporating the effects of trade openness and FDI-based absorptive capacities

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.01*** (3.51)	0.01*** (2.87)	0.02*** (3.37)	0.02** (2.41)	0.03*** (2.89)	0.02** (2.15)	-0.005 (-0.88)	0.01** (2.54)	-0.006 (-0.98)
$\ln(A^{max}/A_i)_{t-1}$	0.02*** (3.52)	0.01* (1.70)	0.01* (1.87)	0.05* (1.98)	-0.01 (-0.45)	-0.005 (-0.30)	0.01* (1.73)	0.02** (2.48)	0.02** (2.06)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.001 (-0.62)		-0.006 (-1.60)	0.002 (0.41)		-0.003 (-0.61)	0.02** (2.02)		0.02** (2.02)
$\ln SCH_{it}$	0.002 (0.27)	-0.01 (-0.96)	-0.01 (-1.06)	-0.03 (-1.43)	-0.03 (-1.36)	-0.03 (-1.44)	0.01* (1.83)	0.002 (0.14)	0.01 (1.39)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.003* (1.67)	0.003* (1.70)		0.01* (1.70)	0.003 (0.91)		0.001 (0.43)	-0.001 (-0.58)
$\ln TO_{it}$	0.002 (0.49)	0.004 (0.80)	0.002 (0.66)	0.006 (0.44)	0.008 (0.42)	-0.004 (-0.80)	0.01 (0.97)	0.004 (0.61)	0.006 (0.90)
$TO_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.02* (1.78)	0.01 (1.18)	0.01 (1.22)	-0.02 (-0.39)	0.05 (0.64)	0.05 (1.52)	-0.001 (-0.09)	0.006 (0.56)	-0.001 (-0.05)
FY_{it}	0.26** (2.38)	0.28** (2.43)	0.32*** (3.37)	0.45* (1.97)	0.64** (2.06)	0.54* (1.74)	0.25* (1.71)	0.38* (1.97)	0.28* (1.99)
$FY_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.04 (-0.38)	-0.06 (-0.58)	-0.13 (-1.58)	-0.45 (-0.66)	-1.27 (-1.43)	-1.19 (-1.23)	-0.06 (-0.49)	-0.14 (-0.96)	-0.07 (-0.57)
Hansen (*p*-value)	0.42	0.31	0.90	0.99	0.99	0.99	0.99	0.98	0.99
Diff-in-Hansen (*p*-value)	0.90	0.72	0.99	0.99	0.95	0.99	0.99	0.99	0.99
AR(2) (*p*-value)	0.54	0.47	0.83	0.11	0.22	0.30	0.61	0.50	0.64

Notes: see notes to Table A1.

Table A8: Fixed Effect Bias-Corrected Dynamic LSDV estimates

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.007* (1.68)	0.01*** (3.01)	0.008** (2.02)	0.009 (0.94)	0.02* (1.93)	0.006 (0.48)	-0.02 (-1.26)	0.01* (1.88)	-0.003 (-0.28)
$\ln(A^{max}/A_i)_{t-1}$	0.05*** (4.69)	0.03** (2.55)	0.03** (2.36)	0.04*** (2.66)	0.05* (1.90)	0.05** (2.11)	0.05** (2.25)	0.04*** (3.43)	0.06*** (4.25)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.004 (1.24)		0.003 (1.34)	0.004 (1.32)		0.006 (1.53)	0.05** (2.16)		0.05** (2.58)
$\ln SCH_{it}$	0.0002 (0.02)	-0.009 (-0.77)	-0.007 (-0.55)	-0.03 (-1.34)	-0.04 (-1.34)	-0.03 (-1.16)	0.03 (1.54)	-0.02 (-1.37)	0.02* (1.68)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.005** (2.49)	0.005** (2.30)		-0.001 (-0.25)	-0.004 (-0.91)		0.003 (1.01)	0.003 (0.86)

Notes: distance to the equator is not considered in the regressions since it is time invariant. The bias correction is initialized by the Blundell and Bond estimator and bootstrap standard errors are used. See also notes to Table A1.

Table A9: TFP growth estimates based on a double-log specification for absorptive capacity measures

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.01***	0.02**	0.01***	0.02***	0.01**	0.03**	-0.003	0.009*	-0.002
	(3.00)	(2.55)	(3.32)	(2.93)	(2.31)	(2.63)	(-0.62)	(1.74)	(-0.38)
$\ln(A^{max}/A_i)_{t-1}$	0.02***	0.01**	0.004	0.04***	0.06**	0.06**	0.01**	0.01*	0.01
	(4.71)	(2.45)	(0.59)	(5.34)	(2.56)	(2.49)	(2.05)	(1.89)	(1.28)
$\ln(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.001		-0.005	-0.02		-0.02	0.02*		0.02*
	(-0.40)		(-1.46)	(-1.38)		(-1.10)	(1.84)		(1.71)
$\ln SCH_{it}$	0.007*	-0.009	-0.01	-0.01	-0.004	-0.01	0.01**	-0.001	0.009
	(1.72)	(-1.26)	(-1.40)	(-0.89)	(-0.23)	(-1.24)	(2.63)	(-0.14)	(0.80)
$\ln SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.009***	0.01**		-0.01	-0.01		0.006	0.001
		(2.62)	(2.33)		(-0.83)	(-0.56)		(1.23)	(0.33)
Hansen (*p*-value)	0.70	0.51	0.78	0.99	0.99	0.99	0.99	0.95	0.99
Diff-in-Hansen (*p*-value)	0.97	0.37	0.99	0.99	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-value)	0.76	0.49	0.75	0.11	0.37	0.12	0.73	0.37	0.69

Notes: see notes to Table A1.

Table A10: Alternative set of control variables

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
$\ln (X/Q)_{it}$	0.01***	0.01***	0.02**	0.04**	0.04*	0.02**	-0.008	0.01**	-0.008
	(2.91)	(2.83)	(2.14)	(2.73)	(1.72)	(2.43)	(-1.00)	(2.13)	(-1.12)
$\ln(A^{max}/A_i)_{t-1}$	0.02***	0.02**	0.02**	0.04*	0.06**	0.06**	0.01*	0.01**	0.01*
	(4.75)	(2.10)	(2.13)	(1.92)	(2.86)	(2.75)	(1.80)	(2.27)	(1.76)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	-0.0003		-0.007	-0.004		-0.001	0.02**		0.02**
	(-0.11)		(-1.01)	(-0.80)		(-0.31)	(2.25)		(2.11)
$\ln SCH_{it}$	0.01**	-0.004	-0.01	-0.06	-0.03	-0.02	0.01**	-0.001	0.02*
	(2.48)	(-0.36)	(-0.66)	(-1.58)	(-1.22)	(-1.12)	(2.48)	(-0.07)	(1.78)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.003	0.004		-0.003	-0.006		0.002	-0.001
		(1.49)	(1.31)		(-0.52)	(-1.21)		(0.81)	(-0.59)
$\Delta \ln TO_{it}$	0.02***	0.02***	0.01**	-0.02	0.0003	0.01	0.02**	0.01*	0.02**
	(3.27)	(3.45)	(2.12)	(-0.63)	(0.01)	(0.51)	(2.30)	(1.78)	(2.71)
ΔFY_{it}	0.15**	0.15**	0.16***	0.01	0.01	0.24***	0.08	0.05	0.10
	(2.31)	(2.33)	(2.79)	(0.15)	(0.07)	(2.85)	(0.97)	(0.78)	(1.27)
ΔINF_{it}	-0.001**	-0.001**	-0.008**	0.10	0.07	0.05	-0.001**	-0.001*	-0.001**
	(-2.11)	(-2.25)	(-2.31)	(1.58)	(1.40)	(0.94)	(-2.17)	(-1.77)	(-2.09)
$\Delta \ln FD_{it}$	-0.01	-0.01	-0.009	0.008	-0.005	-0.01	0.004	0.007	-0.006
	(-1.13)	(-1.14)	(-1.12)	(0.47)	(-0.23)	(-1.26)	(0.38)	(0.59)	(-0.81)
$LOCK_{it}$	-0.005	-0.003	-0.002	-0.01*	0.01	0.01	-0.01**	-0.006	-0.01**
	(-1.17)	(-0.80)	(-0.37)	(-1.88)	(0.81)	(0.93)	(-2.20)	(-1.23)	(-2.21)
Hansen (*p*-value)	0.46	0.38	0.29	0.99	0.99	0.99	0.99	0.87	0.98
Diff-in-Hansen (*p*-value)	0.48	0.48	0.28	0.99	0.98	0.99	0.99	0.86	0.99
AR(2) (*p*-value)	0.13	0.15	0.13	0.83	0.33	0.16	0.28	0.20	0.17

Notes: inflation (*INF*) is measured by changes in the GDP deflator, financial development (*FD*) is proxied by the ratio of M3 to GDP. Landlockness (*LOCK*) is used instead of distance to the equator to control for the effects of geographical location. See also notes to Table A1.

Table A11: Alternative set of external instruments for R&D intensity

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
	All countries (55)			OECD countries (23)			Developing countries (32)		
ln $(X/Q)_{it}$	0.01^{***}	0.02^{**}	0.01^{***}	0.02^{**}	0.02^{**}	0.02^{**}	-0.006	0.01^{**}	-0.005
	(2.88)	(2.57)	(3.03)	(2.06)	(2.68)	(2.61)	(-0.87)	(2.40)	(-0.82)
$\ln(A^{max}/A_i)_{t-1}$	0.02^{***}	0.01^{*}	0.01^{*}	0.03^{**}	0.04^{***}	0.05^{**}	0.01^{*}	0.01^{*}	0.01
	(4.25)	(1.73)	(1.69)	(2.68)	(2.83)	(2.05)	(1.82)	(1.73)	(1.34)
$(X/Q)_{it} \times \ln(A^{max}/A_i)_{t-1}$	0.0007		-0.003	-0.004		-0.001	0.03^{**}		0.03^{**}
	(0.37)		(-0.97)	(-0.95)		(-0.21)	(2.20)		(2.10)
$\ln SCH_{it}$	0.007^{*}	-0.01	-0.01	-0.02	-0.01	-0.01	0.01^{**}	-0.005	0.01
	(1.67)	(-1.37)	(-1.18)	(-1.51)	(-0.49)	(-0.67)	(2.58)	(-0.41)	(1.11)
$SCH_{it} \times \ln(A^{max}/A_i)_{t-1}$		0.004^{**}	0.004^{**}		-0.001	-0.005		0.003	0.0003
		(2.23)	(2.26)		(-0.28)	(-0.98)		(1.09)	(0.16)
Hansen (*p*-value)	0.72	0.50	0.67	0.99	0.99	0.98	0.99	0.94	0.99
Diff-in-Hansen (*p*-value)	0.85	0.36	0.97	0.99	0.99	0.99	0.99	0.99	0.99
AR(2) (*p*-value)	0.65	0.57	0.86	0.11	0.22	0.12	0.73	0.45	0.72

Notes: *effectiveness of legislature* is replaced with *civil liberty* (published by Freedom House) as an alternative external instrument for R&D. See also notes to Table A1.

References

Aghion, P. & P. Howitt (1992) 'A Model of Growth through Creative Destruction', *Econometrica,* 60, 323-51

Barro, R. J. & J. W. Lee (2001) 'International Data on Educational Attainment: Updates and Implications', *Oxford Economic Papers,* 53, 541-63

Basu, S., J. G. Fernald & M. S. Kimball (2006) 'Are Technology Improvements Contractionary?', *American Economic Review,* 96, 1418-48

Bernard, A. B. & C. I. Jones (1996a) 'Comparing Apples to Oranges: Productivity Convergence and Measurement Across Industries and Countries', *American Economic Review,* 86, 1216-38

Bernard, A. B. & C. I. Jones (1996b) 'Productivity Across Industries and Countries: Time Series Theory and Evidence', *Review of Economics and Statistics,* 78, 135-46

Bruno, G. S. F. (2005) 'Approximating the Bias of the LSDV Estimator for Dynamic Unbalanced Panel Data Models', *Economics Letters,* 87, 361-66

Cameron, G., J. Proudman & S. Redding (2005) 'Technological Convergence, R&D, Trade and Productivity Growth', *European Economic Review,* 49, 775-807

Cohen, D. & M. Soto (2007) 'Growth and Human Capital: Good Data, Good Results', *Journal of Economic Growth,* 12, 51-76

de la Fuente, A. & R. Doménech (2006) 'Human Capital in Growth Regressions: How Much Difference Does Data Quality Make?', *Journal of the European Economic Association,* 4, 1-36

Griffith, R., S. Redding & J. V. Reenen (2003) 'R&D and Absorptive Capacity: Theory and Empirical Evidence', *Scandinavian Journal of Economics,* 105, 99-118

Griffith, R., S. Redding & J. v. Reenen (2004) 'Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries', *Review of Economics and Statistics,* 86, 883-95

Griffith, R., S. J. Redding & J. Van Reenen (2000) 'Mapping The Two Faces Of R&D: Productivity Growth In A Panel Of OECD Industries', *CEPR Discussion Papers 2457,*

Ha, J. & P. Howitt (2007) 'Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory', *Journal of Money, Credit and Banking,* 39, 733-74

Howitt, P. (2000) 'Endogenous Growth and Cross-Country Income Differences', *American Economic Review,* 90, 829-46

Jones, C. (1995) 'Time Series Tests of Endogenous Growth Models', *Quarterly Journal of Economics,* 110, 495-525

Keller, W. (2004) 'International Technology Diffusion', *Journal of Economic Literature,* 42, 752-82

Kiviet, J. F. (1999) 'Expectation of expansions for estimators in a dynamic panel data model; some results for weakly exogenous

regressors', in *Analysis of Panel Data and Limited Dependent Variables,* eds. C. Hsiao, K. Lahiri, L.-F. Lee and M. H. Pesaran(Cambridge: Cambridge University Press)

Madsen, J. B. (2008) 'Semi-Endogenous versus Schumpeterian Growth Models: Testing the Knowledge Production Function using International Data', *Journal of Economic Growth,* 13, 1-26

Madsen, J. B., S. Saxena & J. B. Ang (2009) 'The Indian Growth Miracle and Endogenous Growth', *Journal of Development Economics, forthcoming,* (doi:10.1016/j.jdeveco.2009.06.002)

Nelson, R. R. & E. S. Phelps (1966) 'Investment in Humans, Technological Diffusion, and Economic Growth', *American Economic Review,* 56, 69-75

Romer, P. M. (1990) 'Endogenous Technological Change', *Journal of Political Economy,* 98, S71-102

Windmeijer, F. (2005) 'A Finite Sample Correction for the Variance of Linear Efficient Two-step GMM Estimators', *Journal of Econometrics,* 126, 25-51

References

Abromovitz, M. (1986). "Catching Up, Forging Ahead, and Falling Behind." *Journal of Economic History* 46, pp. 386-406.

Aghion, P. and Howitt, P. (1992). "A Model of Growth through Creative Destruction." *Econometrica* 60, pp. 323-351.

____ (1998). *Endogenous Growth Theory*. Cambridge: MIT Press.

____ (2005). "Growth with Quality-Improving Innovations: An Integrated Framework," Aghion, P. and Durlauf, S. N. (Ed), In: *Handbook of Economic Growth.* Amsterdam: Elsevier, 67-110.

Aghion, P.; Howitt, P. and Mayer-Foulkes, D. (2005). "The Effect of Financial Development on Convergence: Theory and Evidence." *Quarterly Journal of Economics* 120, pp. 173-222.

Andrés, J. and Hernando, I. (1997). "Does Inflation Harm Economic Growth? Evidence from the OECD,'' NBER Working Paper No. 6062."

Ang, J.B. (2008). "A Survey of Recent Developments in the Literature of Finance and Growth." *Journal of Economic Surveys* 22, pp. 536-576.

____ (2010). "Finance and Inequality: The Case of India." *Southern Economic Journal* 76, pp. 738-761.

Ang, J.B. and McKibbin, W.J. (2007). "Financial Liberalization, Financial Sector Development and Growth: Evidence from Malaysia." *Journal of Development Economics* 84, pp. 215-233.

Arellano, M. and Bover, O. (1995). "Another Look at the Instrumental Variable Estimation of Error-Components Models." *Journal of Econometrics* 68, pp. 29-51.

Barro, R.J. and Lee, J.W. (2001). "International Data on Educational Attainment: Updates and Implications." *Oxford Economic Papers* 53, pp. 541-563.

Basu, S.; Fernald, J.G. and Kimball, M.S. (2006). "Are Technology Improvements Contractionary?" *American Economic Review* 96, pp. 1418-1448.

Baum, C.F.; Schaffer, M.E. and Stillman, S. (2003). "Instrumental Variables and GMM: Estimation and Testing." *The Stata Journal* 3, pp. 1-31.

Benhabib, J. and Spiegel, M.M. (1994). "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-country Data." *Journal of Monetary Economics* 34, pp. 143-173.

____ (2005). "Human Capital and Technology Diffusion," Aghion, P. and Durlauf, S. (Ed), In: *Handbook of Economic Growth.* Amsterdam: Elsevier, 935-966.

Bernard, A.B. and Jones, C.I. (1996a). "Comparing Apples to Oranges: Productivity Convergence and Measurement Across Industries and Countries." *American Economic Review* 86, pp. 1216-1238.

____ (1996b). "Productivity Across Industries and Countries: Time Series Theory and Evidence." *Review of Economics and Statistics* 78, pp. 135-146.

Blundell, R. and Bond, S. (1998). "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models." *Journal of Econometrics* 87, pp. 115-143.

Bond, S.R.; Hoeffler, A. and Temple, J. (2001). "GMM Estimation of Empirical Growth Models." *Centre for Economic Policy Research Discussion Paper No. 3048*.

Bosworth, B. and Collins, S.M. (2003). "The Empirics of Growth: An Update." *Brookings Papers on Economic Activity* 2, pp. 180-200.

Bruno, G.S.F. (2005). "Approximating the Bias of the LSDV Estimator for Dynamic Unbalanced Panel Data Models." *Economics Letters* 87, pp. 361-366.

Cameron, G.; Proudman, J. and Redding, S. (2005). "Technological Convergence, R&D, Trade and Productivity Growth." *European Economic Review* 49, pp. 775-807.

Coe, D.T. and Helpman, E. (1995). "International R&D spillovers." *European Economic Review* 39, pp. 859-897.

Coe, D.T.; Helpman, E. and Hoffmaister, A.W. (1997). "North-South R&D Spillovers." *Economic Journal* 107, pp. 134-149.

____ (2009). "International R&D Spillovers and Institution." *European Economic Review* 53, pp. 723-741.

Cohen, D. and Soto, M. (2007). "Growth and Human Capital: Good Data, Good Results." *Journal of Economic Growth* 12, pp. 51-76.

Cohen, W.M. and Levinthal, D.A. (1989). "Innovation and Learning : The Two Faces of R&D." *Economic Journal* 99, pp. 569-596.

de la Fuente, A. and Doménech, R. (2006). "Human Capital in Growth Regressions: How Much Difference Does Data Quality Make?" *Journal of the European Economic Association* 4, pp. 1-36.

Durlauf, S.; Johnson, P. and Temple, J. (2005). "Growth Econometrics," Aghion, P. and Durlauf, S. (Ed), In: *Handbook of Economic Growth.* Amsterdam: North-Holland, 555-677.

Easterlin, R.E. (1981). "Why Isn't The Whole World Developed." *Journal of Economic History* 41, pp. 1-19.

Eaton, J. and Kortum, S. (1999). "International Technology Diffusion: Theory and Measurement." *International Economic Review* 40, pp. 537-570.

Engelbrecht, H.J. (1997). "International R&D Spillovers, Human Capital and Productivity in OECD Economies: An Empirical Investigation." *European Economic Review* 41, pp. 1479-1488.

Fagerberg, J. (1994). "Technology and International Differences in Growth Rates." *Journal of Economic Literature* 32, pp. 1147-1175.

Fischer, S. (1993). "The Role of Macroeconomic Factors in Growth." *Journal of Monetary Economics* 32, pp. 485-512.

Gerschenkron, A. (1962). *Economic Backwardness in Historical Perspective*. Cambridge: Belknap Press of Harvard University Press.

Ginarte, J. and Park, W. (1997). "Determinants of Patent Rights: A Cross-National Study." *Research Policy* 26, pp. 283-301.

Griffith, R.; Redding, S. and Reenen, J.V. (2003). "R&D and Absorptive Capacity: Theory and Empirical Evidence." *Scandinavian Journal of Economics* 105, pp. 99-118.

Griffith, R.; Redding, S. and Reenen, J.v. (2004). "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries." *Review of Economics and Statistics* 86, pp. 883-895.

Griffith, R.; Redding, S.J. and Van Reenen, J. (2000). "Mapping The Two Faces Of R&D: Productivity Growth In A Panel Of OECD Industries." *CEPR Discussion Papers 2457*.

Griliches, Z. (1990). "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature* 28, pp. 1661-1707.

Ha, J. and Howitt, P. (2007). "Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory." *Journal of Money, Credit and Banking* 39, pp. 733-774.

Hobday, M. (2003). "Innovation in Asian Industrialization: A Gerschenkronian Perspective." *Oxford Development Studies* 31, pp. 293-314.

Howitt, P. (2000). "Endogenous Growth and Cross-Country Income Differences." *American Economic Review* 90, pp. 829-846.

____ (2005). "Health, Human Capital and Economic Growth : A Schumpeterian Perspective," Lopez-Casasnovas, G., Rivera, B. and Currais, L. (Ed), In: *Health and Economic Growth : Findings and Policy Implications.* Cambridge: The MIT Press,

Hu, A.G.Z.; Jefferson, G.H. and Jinchang, Q. (2005). "R&D and Technology Transfer: Firm-Level Evidence from Chinese Industry." *Review of Economics and Statistics* 87, pp. 780-786.

IMF (2007). *International Financial Statistics 2007 (CD ROM)*. Washington: IMF and World Bank.

Jaffe, A.B. and Palmer, K. (1997). "Environmental Regulation and Innovation: A Panel Data Study." *Review of Economics and Statistics* 79, pp. 610-619.

Jones, C. (1995a). "R&D Based Models of Economic Growth." *Journal of Political Economy* 103, pp. 759-784.

____ (1995b). "Time Series Tests of Endogenous Growth Models." *Quarterly Journal of Economics* 110, pp. 495-525.

Keller, W. (2002a). "Geographic Localization and International Technology Diffusion." *American Economic Review* 92, pp. 120-142.

____ (2002b). "Trade and the Transmission of Technology." *Journal of Economic Growth* 7, pp. 5-24.

____ (2004). "International Technology Diffusion." *Journal of Economic Literature* 42, pp. 752-782.

Kiviet, J.F. (1999). "Expectation of expansions for estimators in a dynamic panel data model; some results for weakly exogenous regressors," Hsiao, C., Lahiri, K., Lee, L.-F. and Pesaran, M. H. (Ed), In: *Analysis of Panel Data and Limited Dependent Variables.* Cambridge: Cambridge University Press, 199-225.

Kneller, R. (2005). "Frontier Technology, Absorptive Capacity and Distance." *Oxford Bulletin of Economics and Statistics* 67, pp. 1-23.

Kneller, R. and Stevens, P.A. (2006). "Frontier Technology and Absorptive Capacity: Evidence from OECD Manufacturing Industries." *Oxford Bulletin of Economics and Statistics* 68, pp. 1-21.

Madsen, J.B. (2007). "Technology Spillover through Trade and TFP Convergence: 135 Years of Evidence for the OECD Countries." *Journal of International Economics* 72, pp. 464-480.

____ (2008a). "Economic Growth, TFP Convergence and the World Export of Ideas: A Century of Evidence." *Scandinavian Journal of Economics* 110, pp. 145-167.

____ (2008b). "Semi-Endogenous versus Schumpeterian Growth Models: Testing the Knowledge Production Function using International Data." *Journal of Economic Growth* 13, pp. 1-26.

____ (2009). "Trade Barriers, Openness, and Economic Growth." *Southern Economic Journal* 76, pp. 397-418.

Madsen, J.B. and Davis, P. (2006). "Equity Prices, Productivity Growth and 'The New Economy'." *Economic Journal* 116-513.

Madsen, J.B.; Saxena, S. and Ang, J.B. (2009). "The Indian Growth Miracle and Endogenous Growth." *Journal of Development Economics, forthcoming* (doi:10.1016/j.jdeveco.2009.06.002).

Mauro, P. (1995). "Stock Markets and Growth: A Brief Caveat on Precautionary Savings." *Economics Letters* 47, pp. 111-116.

Nelson, R.R. and Phelps, E.S. (1966). "Investment in Humans, Technological Diffusion, and Economic Growth." *American Economic Review* 56, pp. 69-75.

Rodrik, D.; Subramanian, A. and Trebbi, F. (2004). "Institutions Rule: The Primacy of Institutions Over Geography and Integration In Economic Development." *Journal of Economic Growth* 9, pp. 131-165.

Romer, P.M. (1990). "Endogenous Technological Change." *Journal of Political Economy* 98, pp. S71-102.

Roodman, D. (2009). "How to Do xtabond2: An Introduction to Difference and System GMM in Stata." *The Stata Journal* 9, pp. 86-136.

Savvides, A. and Zachariadis, M. (2005). "International Technology Diffusion and the Growth of TFP in the Manufacturing Sector of Developing Economies." *Review of Development Economics* 9, pp. 482-501.

UNESCO (various issues). "Statistical Yearbook."

Verspagen, B. (1991). "A New Empirical Approach to Catching up or Falling behind." *Structural Change and Economic Dynamics* 2, pp. 359-380.

WDI (2007). *World Development Indicators 2007 (CD ROM)*. Philadelphia: World Bank.

Windmeijer, F. (2005). "A Finite Sample Correction for the Variance of Linear Efficient Two-step GMM Estimators." *Journal of Econometrics* 126, pp. 25-51.

World Intellectual Property Organization (WIPO) (2007). "WIPO Patent Report: Statistics on Worldwide Patent Activity."

Xu, B. (2000). "Multinational Enterprises, Technology Diffusion, and Host Country Productivity Growth." *Journal of Development Economics* 62, pp. 477-493.

Zachariadis, M. (2003). "R&D, Innovation, and Technological Progress: A Test of the Schumpeterian Framework without Scale Effects." *Canadian Journal of Economics* 36, pp. 566-586.

____ (2004). "R&D-Induced Growth in the OECD?" *Review of Development Economics* 8, pp. 423-439.