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R&D and Development

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Abstract

Lederman and Maloney trace the evolution of research and development (R&D) expenditures along the development process using a new global panel data set. They show that R&D effort measured as a share of GDP rises with development at an increasing rate. The authors examine how four groups of countries from Latin America, Asia, advanced manufacturing exporters, and advanced natural resource-abundant countries fare relative to the predicted development trajectory. Latin America generally underperforms as do some countries in Asia and Europe, but their striking finding is that some—Finland, Israel, the Republic of Korea, and Taiwan (China)—have radically deviated from the predicted trajectory and displayed impressive R&D takeoffs. The authors ask whether these countries overinvest in R&D but find that the high estimates of the social rates of return probably justify this effort. Moreover, the returns to R&D decline with per capita GDP. The authors attempt to explain why rich countries invest more in R&D than poor countries. They conclude that financial depth, protection of intellectual property rights, government capacity to mobilize resources, and the quality of research institutions are the main reasons why R&D efforts rise with the level of development.

This paper—a product of the Regional Studies Program, Office of the Chief Economist, Latin America and the Caribbean Region—is part of a larger effort in the region to understand the role of innovation in development. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Patricia Soto, room I8-018, telephone 202-473-7892, fax 202-522-7528, email address psoto@worldbank.org. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at dlederman@worldbank.org or wmaloney@worldbank.org. April 2003. (38 pages)

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R&D and Development

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I. Introduction

The literature suggests that roughly half of cross-country differences in per capita income and growth are driven by differences in Total Factor Productivity, generally associated with technological progress.[2] This fact moves to center stage an abiding question in economic development: why do developing countries, with great potential gains from adopting technologies from the industrialized countries, fail to do so? In fact, perversely, the countries generating new technologies at the frontier appear to have faster TFP growth in manufacturing and agriculture than the poor countries who could, in theory, simply adopt.[3]

However, recent work in innovation stresses that adopting existing technology is not without cost. Firms and countries need to develop an "absorptive" or "national learning" capacity which, in turn are hypothesized to be functions of spending on research and development (R&D).[4] Though often considered relevant only for basic science, Cohen and Levinthal (1991) among others stress learning -- knowing where the frontier is and figuring out what adaptations are necessary -- as the "second face" of R&D. In fact, Pavitt (2001) argues that investment in pure research is also important for developing countries. First, those most familiar with the frontiers of basic science will best train the applied problem solvers in the private sector. Second, even basic research does not flow easily or costlessly across borders so developing countries cannot simply rely on what is being generated in the advanced countries.

This paper investigates three outstanding issues that are central to understanding the links between innovation and development. We first generate stylized patterns of the evolution of R&D spending over the course of development employing a new panel data set· constructed by Lederman and Saenz (2003). The evidence shows that R&D rises exponentially with the level of development measured by GDP per capita. Provocatively, we also identify several striking outliers such as Taiwan and Korea in East Asia, Finland

[2] See Hall and Jones (1999), Dollar and Wolf (1997).
[3] Martin and Mitra (2001)
[4] At the firm level, see Cohen and Levinthal (1990), Forbes and Wield (2000), Griffith, Reddıng and Van Reenen (2003), Pavitt (2001) at the national level see, for example, Baumol, Nelson and Wolf (1994).

and Israel among the industrialized countries, and even poor China and India that experienced a "take off" that dramatically diverges from the median trajectory observed in the global data.

Second, we ask whether the success of several of these countries was due partly to their deviation from the standard path, suggesting that developing countries need to greatly upgrade their R&D efforts, or were these innovation "over-achievers" engaged in wasteful spending? To approach these questions we follow an emerging literature that estimates the social rates of return to R & D. Virtually all studies have used U.S. industry and firm level data and found extremely high social rates of return ranging from 71% (Griliches and Lichtenberg 1984) to over 100% (Terleckyj 1980 and Scherer 1982). Only three studies to date use cross country data, thereby presumably capturing intra-country spillovers. Coe and Helpman (1995) estimate rates of return to R&D of 123% for the G7 and 85% for the remaining 15 OECD countries; van Pottelsberghe de la Potterie and Lichtenberg (2001) find returns of 68% in the G7 and 15% for a subset of the remaining OECD countries. At the long run US cost of capital of 7%, these estimates imply that the optimal levels of R&D should be multiples of their present levels.

To date, the literature relative to developing countries is extremely thin. Lichtenberg (1994) works with a cross section of 53 countries and argues that the return to private R&D is seven times larger than to fixed investment. Coe, Helpman and Hoffmaister (1997) and a sub-sequent literature (Keller 2001) estimate the impact of *foreign* R&D on manufacturing TFP growth in developing countries. These authors argue that because developing countries' own R&D expenditures are so low, they can be ignored. The data employed here suggest that developing-country R&D is not necessarily insignificant relative to the size of their economies, and more importantly, the returns are substantial. In fact, the returns to R&D in developing countries are above those for industrialized countries.

Our estimation strategy attempts to deal with several issues raised in the existing literature, particularly those employing single cross sections, related to unobserved country heterogeneity and the likely endogeneity of R&D. For instance, Barro and Sala–

I-Martın (1995, 352) find the reported rates of return to be implausibly high and speculate that they are due to reverse causality going from productivity growth to R&D expenditures.

A third question naturally emerges from the aforementioned analyses: If the returns are so high in poor countries, why do rich countries invest more in R&D as a share of GDP? To answer this question we explore potential determinants of R&D across countries and over time. We find that the depth of domestic credit markets, educational variables, the extent of protection offered to intellectual property rights (IPRs), the ability to mobilize government resources, and the quality of complementary academic institutions influence cross-country differences in R&D, and a subset of these variables together completely eliminate the apparent effect of the level of development on R&D effort.

A recurring question throughout the paper is whether and how much of the patterns observed across countries can be explained by their endowments of natural resources. Numerous authors (see for instance, Sachs and Warner 2001, Matusyama 1991) argue that the prospects for productivity growth are intrinsically lower in these sectors than in manufacturing. Lower potential for TFP growth could imply lower rates of rates of return to R&D and hence lower investment.

The rest of the paper is organized as follows. Section II focuses on innovation trajectories during the development process by discussing the data and the corresponding results. Section III discusses basic concepts and methods used for estimating the social rates of return to R&D. Section IV then explores the determinants of R&D. Section V summarizes the main findings.

II. Innovation Trajectories: R&D Expenditures and Development

The data were drawn from a data base constructed by Lederman and Saenz (2003) for a broad cross section of countries from the 1960s to the present. Further detail on the construction of the series is available there but the core data on R&D was drawn from

UNESCO, The World Bank, OECD, the Ibero American Science and Technology Indicators Network (RICYT)[5] and the Taiwan Statistical Data Book. The definition of R&D in all these surveys is the same and "includes fundamental and applied research, as well as experimental development." [6] The data thus include not only the basic science expected in the more advanced countries, but also investments in the adoption and adaptation of existing technologies often thought more germane to developing countries.

Though it would be desirable to study the evolution, rate of return to, and determinants of private R&D, we work with aggregate R&D for several reasons. First, the data sources divide R&D not into private and public R&D, rather they distinguish between productive and non-productive sectors, the latter accounting for roughly 20% of the total.[7] The definition of "productive sector" includes both public and private for profit and not-for profit firms while "non-productive sector" includes R&D financed or undertaken by the executive branch of government. Since the productive sector may well include mining, public utilities or other state owned enterprises, the exercise of analyzing how its R&D evolves and its rate of return relative to that of non-productive sector is less interesting than the public/private sector split.

Second, this division seems to occasionally lead to some critical issues in categorization. For instance, if a public company finances its R&D from retained earnings, this will count as productive sector R&D. If instead that R&D is financed by a transfer from the treasury to the firm, it counts as "non-productive" R&D. For several countries in our sample, there were striking shifts in composition from one year to the next suggesting such sensitivity to accounting practices. In contrast, the total R&D series were reasonably stable. The final consideration is more prosaic: many developing countries tabulate only the aggregate values and as they are the focus of this paper, we want to include as many as possible.

[5] Red Iberoamericana de Indicadores de Ciencia y Tecnología
[6] UNESCO Statistical Yearbook (1980) pg 742. Definitions are common to the OECD, RICYT, World Bank and all are based on the Frascatti manual definition.
[7] The median for countries with both series is 21%.

Figure 1a plots the predicted and observed levels of R&D as a share of GDP as function of the log GDP per capita. The predicted value is generated from a regression of the log of the ratio of total R&D expenditures to GDP on log GDP per capita and its squared term. Due to concerns about the influence of outliers, this model was estimated as a median regression. The estimated coefficients are presented in the first column of Table 1, and Figure 1a illustrates the resulting positive relationship between R&D effort and log GDP per capita. It is clear from this evidence that R&D expenditures/GDP rise with development and that the rate of increase also rises with GDP per capita. Though the apparent curvature is partly a function of the log transformation of GDP per capita employed to more clearly display the differences among poor countries, the elasticities estimated in Table 1 eventually exceed unity suggesting that the second derivative is, in fact increasing. The fixed effects estimates in column 2 indicate that the non-linear positive relationship between R&D and the level of development is a phenomenon that occurs within countries, and it is not an exclusive feature of the cross-country variations.

Figure 1b presents a first cut at looking at how a few select countries from several regions compare to the predicted value. What is immediately striking is that Korea, Finland, and Israel show substantial "take offs" relative to the median trajectory. Two Latin American countries, Argentina and Mexico, which had similar levels of income as Korea and Israel prior to their take off hover on or below the predicted value for their level of development. Both China and India appear to be following more in the footsteps of the "take off" countries than the Latin Americans.

Figures 2a-d present the residuals from a more general and flexible specification that includes log GDP, log GDP squared, log labor force, and log labor force squared, and year dummies as explanatory variables. This allows for independent effects related to the size of the economy and size of the labor force rather than per capita income or development per se. In this case, the predicted value is captured by the horizontal axis and we observe the evolution of country R&D effort across time as opposed to across income levels. The selection of countries reflects the availability of data in the case of the developing countries and an attempt to present a broad cross section of types of countries. For the developing world, we focus on Latin America and Asia. Africa's data is of generally poor quality and the time series from the emerging Eastern European are still relatively short.

The results broadly support the conclusions from figures 1. Both Korea and Taiwan show impressive rises to roughly 100 percent above median levels in the early 1980s that continue to this day. Both India's and China's residuals suggest long standing above median investment that seems to have declined somewhat in the 1990s. This appears due not so much to a decline in the absolute amount of R&D spending, but rather some lag in keeping up with the relatively high growth rates of this period. This highlights, in particular, the achievements of Korea and Taiwan in maintaining an increasing level of R&D in periods where GDP was growing at rates close to 10% per year. The two little tigers, Thailand and Indonesia, show very different trajectories suggesting that they are, in fact, not following closely in the footsteps of the successful Asian economies in the innovation dimension. The decline starts long before the crisis of the late 1990s and most of the trend is due more to a stagnation of R&D spending in the face of rising GDP than absolute falls.

The new benchmarking presents a more pessimistic view of the evolution of Latin America's R&D effort. Argentina and Chile are only very rarely above the median with Chile the most consistent performer near the median. In the cases of Argentina, and to a lesser extent, Venezuela and Chile, R&D effort has declined secularly relative to the median. The rest of the region has muddled along at roughly 50% of the median for much of the period, although Latin American countries seem to have approached the conditional median in the late 1990s. Given the sharp falls in incomes in most of these countries during the lost decade of the 1980s, the stagnation or decline relative to the median represents absolute declines in total innovation effort.

Two questions immediately come to mind. The first is whether the low R&D spending is to some degree a result of specialization in natural resource intensive products. It is striking that Indonesia and Thailand as well as Latin America are natural resource abundant countries as reflected in high net exports of resource intensive commodities as defined in Leamer (1984). However, Figures 2c casts some doubts about such a link between R&D and natural resources. While the overall goal is to present the trajectories of more advanced countries, we divide the sample into those advanced countries that are ranked as abundant in factors used intensively in manufactured exports (2c) and those abundant in natural resources (2d). What is striking is that Finland, Sweden and the Netherlands, all resource abundant are consistent over performers while Canada, Australia and Ireland are pretty consistently at the median. In, fact, Trefler (1999) argues that Canada's very average performance is partially responsible for Canada's lack luster performance relative to the U.S.

The more manufacturing oriented countries, also show a very diverse picture. Israel and Switzerland have shown consistently above median performance with Israel's trajectory since 1975 especially striking (see Trajtenberg 2001 for a discussion). Japan and the U.S. pretty much defined the trend although they slipped below the median in the 1990s. It is worth mentioning that at higher levels of income the sample becomes very thin so the benchmarking becomes somewhat less informative. The U.S. and Japan invest very high shares of GDP in R&D but Switzerland invests more so the first two appear "below median." Spain has slowly emerged to join Italy at more or less Latin American levels of underperformance.

These findings naturally lead to the second question of whether the unusually high levels of R&D in some countries, and particularly the dramatic takeoffs of Finland, Israel, Korea, and Taiwan were justifiable investments or whether in some sense they may reflect a new type of technological white elephant. All are very successful countries, but to what degree do they owe this to their efforts in R&D? To answer this question we turn to an analysis of the social rates of return to R&D in the following section.

III. Rates of Return to R&D Expenditures

A. The standard framework

A simple production function (see Jones and Williams 1998)

$$Y = K^{\beta_k} L^{\beta_l} S^{\beta_s}$$

where Y is the level of output, K the level of physical capital, L the labor stock and S the stock of accumulated R&D, can be rewritten as

$$\Delta \ln Y = r_k (\frac{I}{Y}) + r_s (\frac{\dot{S}}{Y}) + \beta_l \Delta \ln L$$

by using the fact that

$$\beta_x \Delta \ln(X) = r_x (\frac{\dot{X}}{Y}) = r_x (x) .$$

Here r_x is the rate of return on factor X, x is the share of investment in X over Y, and β_x is the output elasticity of factor X . If we remove the influence of physical factors to get TFP then the social rate of return to R & D is

$$r_s = \Delta \ln TFP / s$$

where s is the share of R&D spending in income. The optimal level of R&D expenditure occurs where r_s= r, the real interest rate. So, the ratio of the optimal level of R&D investment to actual along a balanced growth path can be expressed as the ratio of the social rate of return to R&D over the real interest rate or opportunity cost:

$$\frac{s^*}{s} = \frac{r_s}{r}.$$

Jones and Williams argue that for a very conservative estimate of 28% return to R&D in the US, a long run 7% rate of return on the stock market over the last century suggests that the U.S. should be investing perhaps 4 times the present R&D level observed in this country, which averaged approximately 2.6% of GDP during 1995-2000.

B. Estimation of the rates of return

We begin with a basic specification that can nest much of the existing work on the empirics of economic growth:

$$\dot{y}_{i,t} = \gamma \ln y_{i,t-1} + \beta' X_{i,t} + \alpha s_{i,t} + \mu_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

Where y_{it} dot is the log difference of per capita GDP of country i in period t, $y_{i,t-1}$ is log income per capita at the beginning of the period, X the matrix of conditioning variables, in this case the growth of labor, s_{it} represents investments in both physical and innovative capital expressed as a share of income. μ_i is an individual country fixed effect, μ_t is a sample-wide time effect, and ε_{it} is a country and time specific effect.

One important type of omitted variable bias might be induced by the correlation of unobserved country-specific factors and the variables of interest; $E(\mu_i, s_{it})$ may be large. Casselli, Esquivel and Lefort (1996), for instance, pointed out that the difference with respect to the highest level of income in the sample of countries (i.e., the level to which the other countries are converging) acts as a proxy of the country-specific effect in cross sectional regressions, and thus the resulting estimates are inconsistent.

Panel data offers the only real solution to the endogeneity problem through the use of lagged values as instruments for endogenous variables. The issue of unobserved country specific effects can also be addressed although the standard fixed or variable effects estimators are not consistent in the present context that implicitly includes a lagged dependent variable -- the initial level of GDP per capita. The assumption of a lack of correlation between μ_i and the explanatory variables required for variable effects estimators is not defensible in this context since both y_t dot *and* y_{t-1} are a function of μ_i. On the other hand, OLS is clearly inconsistent and FGLS is also if the errors show either heteroskedasticity or serial correlation (Sevestre and Trognon 1996). Further, the usual elimination of μ_i by subtracting the country mean induces a negative correlation between the transformed error and the lagged dependent variables of order 1/T, which, in short panels such as those used here remains substantial. If at least one of the explanatory variables is truly exogenous, Balestra and Nerlove (1996) show that its lags can be used as instruments and will yield consistent estimates. However, in the present case, it is difficult to assume that any of our variables are strictly exogenous.

Following Anderson and Hsiao (1982), Arellano and Bond (1991) and Caselli et. al. (1996) in the growth literature, we therefore difference the data to eliminate *i*, thus yielding:

$$\Delta \dot{y}_{i,t} = \gamma \Delta \ln y_{i,t-1} + \beta' \Delta X_{i,t} + \alpha \Delta s_{i,t} + \Delta \mu_t + \Delta \varepsilon_{i,t}, \qquad (2)$$

Any unobserved country fixed effects disappear in the differenced errors. However, unless the idiosyncratic error followed a random walk, this differencing necessarily gives the transformed error a moving-average, MA(n), structure that is correlated with the differenced lagged dependent variable. This can be overcome by using instruments dated t-n and earlier. Arellano and Bond (1991) employ lagged levels as a proxy for differences in a Generalized Method of Moments (GMM) context. However, in growth regressions where the explanatory variables (e.g. schooling, natural resource endowments) show little variation over time, levels are often poor instruments. For this reason, Levine, Loayza, and Beck (2000) in their examination of the impact of financial variables on growth follow Blundell and Bond (1998) and Arellano and Bover (1995) in employing a system estimator that rescues some of the cross-sectional variance that is lost in the differences GMM estimator by estimating a system of equations that also includes equation (1) in levels, but with the lagged differences of the endogenous variables as instruments. Bond et al. (2001) show that the "weak instruments" problem can be severe in cross-country growth regressions with panel data. Therefore we follow them, as well as Levine et al. (2000) in applying the GMM *system* estimator to our growth models.

We follow Griliches (1995) in estimating the growth regression as in equation (2), rather than estimating the TFP residual first and then using that residual as the dependent variable of R&D. The single regression approach is superior in this case, because we are interested in the returns to R&D investment relative to physical capital investments and thus we want to retrieve mutually consistent estimates of the returns for both variables.

C. Results

The core data combines the R&D data with that of Summers and Heston (1991) panel updated to 2000 and the Leamer measure of resource endowments. We estimate the corresponding growth regressions using panel data of five-year averages between 1975-2000. Table 2 presents estimated returns to R&D for the panel of countries that had sufficient consecutive observations (at least three) required for the GMM system estimator. All the regressions pass the Sargan test for the validity of the instruments and there is no evidence that they suffer from residual second order serial correlation.[8] Column 1 indicates that, for the largest possible sample, returns to R&D as a whole are around 78%. This estimate falls in the middle of those previously cited estimates for the U.S. and the OECD estimates from Coe and Helpman (1995).

To see if this aggregate number is hiding variation across different levels of development either across countries or within countries, we interact the R&D term and the physical investment term with per capita GDP. The negative R&D interaction term in column 2 suggests a *decreasing* return to R&D with development. This is consistent with the intuition of numerous conditional convergence regressions in the Barro (1991)

[8] The null of the Sargan test is that there is no correlation between the errors and the instruments. Thus a high p-value indicates that the instruments are not correlated with the errors.

tradition: It is likely that a dollar's worth of R&D buys greater increases in productivity for countries far from the technological frontier than for innovating countries who must invent the new technologies that push the frontier forward. Figure 3 plots the predicted values of both R&D and physical investment. The return in the average OECD country is somewhere between 20-40%. For medium income levels, such as Mexico and Chile, the average return is around 60% and for relatively poor countries, such as Nicaragua, the average return is closer to 100%.

Figure 3 also plots the estimated return to physical capital, which column 2 also suggests is decreasing in level of development. As a first conservative approximation, we treat this as the cost of investment resources and hence the ratio of the two returns gives us the ratio of optimal R&D investment to actual. For the U.S., the gap of 2.25 is somewhat more moderate than that offered by Jones and Williams (1998). The return to R&D rises for poorer countries, but given that return to physical capital also rises, their ratio also remains under 2.5. Since the high rate of return to physical investment in developing countries may reflect the risk or other factors that would drive a wedge between it and the true cost of borrowing, this calculation may be excessively conservative. If instead, we go to the other extreme of assuming free access to international capital markets and that the opportunity cost of capital is the 20^{th} century's return on the U.S. stock market of roughly 7%, as suggested by Jones and Williams, the gap for countries of Mexico's or Chile's development level would rise closer to 8. This would suggest that the deviations from the central tendency exhibited by Israel, Finland, Korea and Taiwan were fully justifiable by the rates of return to R&D.

The remaining columns of Table 2 introduce other variables that may explain the returns, but whose availability reduces the sample by 10 countries and, for several countries, the observations available for use as instruments from the 1960s thus shortening the overall period of estimation as well. Column 3 repeats the specification in column 1 with the reduced sample, and we immediately see that the returns to R&D have now risen to 133% and those of physical capital to 18.9%.[9] The dramatic rise of the former is likely to be an artifact of the countries that were dropped, which include Colombia, Guatemala, Iran, Jamaica, Jordan, Malta, Mauritius, Togo and Zambia, which could be under-performers relative to the average returns to R&D among poor countries. Nonetheless, the returns are clearly sensitive to the sample of countries and thus the results should be interpreted with some caution.

Column 4 adds both the tertiary education enrollment rate as a possible fourth production factor and the Leamer net exports of natural-resource intensive exports to control for postulated impacts of natural resources on growth through the investment, education, or R&D channels. Higher education does appear to have a positive rate of return and natural resource abundance appears positively correlated with growth, consistent with Lederman and Maloney (2003). The coefficients on the other factors do not change dramatically as a result although the return to R&D now falls to 102%. Columns 5 and 6 interact the physical capital and R&D investment terms with GDP per capita and, in addition, the R&D and resource abundance terms to see whether resource abundance in fact hampers innovation based growth.

Column 7 confirms the declining returns to R&D and physical capital with development. It also suggests that R&D and natural resources are strong complements; the returns to R&D rise with natural resource exports and vice-versa. This is consistent with Martin and Mitra's (2001) finding that agriculture has experienced a much faster rate of TFP growth than manufacturing in most developed and developing countries. It is also consistent with the argument that the better performance of, for instance, Scandanavia or Australia in their exploitation of natural resources compared to Latin America can be explained by their much higher R&D effort and other innovation-related policies (Maloney 2002). Since the Sargan tests rejects the adequacy of the instrument set, column 6 represents is the most complete well specified regression achievable, although it drops the physical capital interactive term. The previous results hold.

[9] In fact, putting in education alone decreases the sample by 5 countries but somewhat counterintuitively pushes the return to R&D to 98%. This is likely to be due to the same selection issue discussed below.

The previous findings that poor countries invest less in R&D than rich countries and that the returns to R&D are higher in poor countries beg the question of why poor countries invest less in R&D. The following section addresses this question.

IV. Determinants of R&D: Why Do Rich Countries Spend More than Poor Countries?

A. Related literature and data

There are very few studies of the determinants of R&D across countries. Two such studies (Varsakelis 2001; Bebczuk 2002) suffer from small samples and, as result, inconsistent estimates due to inability to deal with country-specific effects and endogeneity of the explanatory variables. Here we again apply the GMM system estimator to our larger sample.

We begin by analogy to the investment literature (see Servén 2003, for example) assuming equilibrium where the marginal product equals the cost of borrowing, but then ask what factors may impede this equalization and hence explain why, given the high estimated rates of return, we do not observe more R&D investment.

We first include a proxy for the long term real cost of borrowing. As a first approximation, we employ the nominal 30-90 day lending rate deflated by the CPI. Though this has the most international coverage in the IMF *International Financial Statistics*, it is still not complete. Further we eliminate countries showing negative real interest rates or values above 40% which we assume are unsustainable long run levels, and capturing stabilization problems, as was the case in Argentina and Brazil in the 1980s. Together, these imply a reduction in the sample to 30 countries. As a second alternative we include the actual gross fixed investment rate which we presume reflects the opportunity cost of investment as well as other factors pertaining to the investment climate. A disadvantage is that the impact of other variables determining R&D investment must be interpreted as effects beyond what they may have on physical investment. Finally, we follow David et al. (2000) arguments in including a measure of credit market depth measured as the ratio of credit to the private sector relative to GDP to proxy for the availability of credit at the reported interest rate.

A second set of variables seeks to capture risk associated with long term investments. Following Servén (2003) we include the variance of GDP which he found correlated with physical investment.

We also include a measure of intellectual property rights that would also affect the expected quasi rents derived from innovation. Although the impact of IPR is theoretically ambiguous (Horstmann et. al 1985), Arora, Ceccagnoli and Cohen (2003) using US manufacturing survey data find that patent protection stimulates R&D across almost all industries. For this purpose we use the IPR index constructed by Park (2002).

To control for the fact that we are using a series of total R&D expenditures, which includes private and public financing of R&D, we include a measure of overall government spending over GDP as a measure of the government's capacity to mobilize resources.

As possible further constraints on investment, we include measures of the availability of complementary innovation-related institutions that may also put binding constraints on new R&D projects. We include the subjective indicators from the *Global Competitiveness Report* (GCR) published by the World Economic Forum on the quality of research institutions (universities, public research centers, etc) and the extent to which these collaborate effectively with the private sector. These considerations may also constrain the number of national innovation projects. Due to the limited time coverage of these two variables, we use the average of the available observations from the late 1990s and assume that these change little over time.

Finally, we include the Leamer indicator of natural resource abundance to see if there is evidence of special barriers to R&D investment in natural resource abundant countries that may somehow explain the especially high rates of return found there.

In all specifications we include as control variables the lagged dependent variable, GDP growth to capture cyclical or accelerator effects, and the log of GDP/capita which we know from section II is positively associated with the R&D effort. Finding correlates that eliminate this last effect and explain why richer countries invest more is a key goal of the exercise.

B. Results

Tables 3a presents the results using the real interest rate and reduced sample. Table 3b presents those with the fixed investment proxy. Both sets of models were estimated using the GMM system estimator. We begin with the core specification including the proxy for the opportunity costs of investment. Since the samples are of modest size, we first individual add variables to the core specification test for their significance and their impact on the level of development variable. Finally, the last columns attempt, to the degree the samples permit, the inclusion of several of these variables together. The increased number of instruments leads to a deterioration in the power of the Sargan tests, particularly in the small sample. In all specifications, with the exception of those specifically mentioned, the Sargan and serial correlation tests are satisfactory.

In both specifications, column 1 shows similar estimates of the lagged dependent variable and level of development which, in the former case, are reasonably robust across specifications. The control for cyclical influences, the GDP growth variable, is consistently positive and significant in the larger sample although less consistently in the smaller one.

The real interest rate has the expected negative sign in all but one specification and is often although not uniformly significant. This intermittence is commonly found in the investment literature (see Serven 2003) but the overall impression is that higher borrowing costs do lead to lower investment in R&D. The investment proxy offers less intuitive results, entering negatively in virtually all but one specification, and is often significant. This may suggest competition among the two types of investment for savings as opposed to a complementary fixed resources. In fact, simple scatterplots suggest that while R&D/GDP rises with development, I/GDP follows an inverted U, perhaps reflecting the diminishing role of physical capital in economies more dependent on innovation for their growth. As we will see, however, the variable is still picking up key elements of the investment environment.

Private credit in both specifications enters with the predicted positive sign indicating that deeper capital markets facilitate R&D investments. Among the measures of risk, the standard deviation of growth enters with the expected negative sign in the interest rate specification and makes the interest rate coefficient significant. In the investment specification, the risk variable has the expected positive sign but it is not significant. However, this appears to be because the investment rate is already capturing it. Dropping investment from the specification makes macro-economic risk enter significantly. In both specifications, the IPR protection index has the expected positive and very significant coefficient. In the larger sample, it causes a reduction in the magnitude of the level of development proxy by roughly half although no such effect is found in the smaller sample.

The same is true for the proxy for the government's ability to mobilize resources. Of interest is also that the physical investment proxy now becomes insignificant but with the expected positive sign. The negative correlation of the two may reflect a reverse causality from that postulated: a greater government effort in R&D has the impact of crowding out physical investment. The results from the smaller sample tell perhaps a different but reasonable story. Once we control for the government contribution to R&D, the private component is more sensitive to interest rate movements than the aggregate value. Also worth noting is that a larger ability to mobilize resources appears to account for roughly half of the impact of the GDP/capita variable on R&D effort in the large sample and a quarter in the small.

Both measures of complementary research capacity enter strongly significantly and with predicted sign in both samples. Of equal interest is that the introduction of the quality of research institutions variable eliminates the influence and significance of the level of development variable and reduces its magnitude and significance in the large sample. What is suggested is that, of any single variable, the dearth of quality research institutions is the most influential in explaining why R&D projects with very high expected returns go unexploited in the developing world. Finally, a negative and significant relationship emerges between Leamer's measure of resource abundance and R&D spending in both specifications.

Combining these variables in one specification degrades the Sargan test in both specifications and our treatment here is cautious. In the large sample, the IP, private credit, and government consumption variables maintain their significant and positive effects. We lose three countries introducing the Leamer measure, and the Sargan tests become unacceptable (not shown) but the previous results are preserved and the sign on natural resources is again negative. Though losing its significance in the specification in column 9, the quality of research institutions variable also becomes significant and positive again in the reduced sample with the Leamer measure, but again with an excessively high p-value for the Sargan test. More importantly, the level of development is not significant in any of these comprehensive specifications.

The small sample estimates using the real interest rate proxy are more fragile but we report even the specifications with exaggerated p-values of Sargan tests because they are suggestive and broadly consistent with those just discussed. Column 9 suggests that again, the IP index, government spending and the quality of research institutions measure remain significant and eliminate the effect of the level of development. In the alternative specification in column 10, dropping the IP index and including the private credit depth variable causes the latter to appear at the 12% significance level, and the former to become significant at the 10% level.

Hence the evidence suggests that the level of development is positively correlated with R&D effort mainly because rich countries tend to have better IP protection, deeper credit markets, higher government capacity to mobilize public R&D expenditures, and in all likelihood, the better quality of the research institutions.

The negative sign on natural resource abundance merits further attention, especially since the returns to R&D rise with net exports of natural resources The most straightforward explanation may simply be definitional. R&D data "[do] not include research on the soils for agricultural purposes, for oceanography serving the fishing industry, concerning the economic exploitation of sources of raw materials, fuel and energy, nor concerning the use of satellite techniques for communication applications" (UNESCO 1980 p 743). It is not obvious why soil research or oil exploration, which have very clear implications for productivity, should be excluded, but it is likely that countries specializing in natural resources will have uncounted research expenditures. The high estimated returns to R&D in natural resource rich countries may also be partially due to upward bias to the degree that research effort in these economies is under-estimated by the available R&D data.

Alternatively, perhaps the low R&D investment in resource abundant countries occurs because the rents or market power associated with natural resource exploitation allow these economies to perform relatively well over the medium term without much innovation effort (Landes 1998): though the Netherlands, Finland and Sweden have chosen a high innovation path, Latin America, Indonesia and Thailand are perhaps more representative of resource rich economies that have followed a low innovation path. This is consistent with Howitt and Mayer's (2002) model of convergence clubs and Maloney's (2002) application of it to explain Latin America's disappointing natural resource performance.

V. Summary of Findings

This paper traced the evolution of innovation indicators along the development process using international data on R&D expenditures. The first part of the paper illustrated how R&D expenditures vary with the level of development. As expected, R&D effort rises with development but at an increasing rate. In turn, the paper examined how different groups of countries (Latin America, East Asia, and natural-resource-rich countries from the OECD) fare relative to what is expected from their GDP and labor force. We found that Latin America under-performs relative to the predictions, but the other country groups significantly over-perform.

Does this mean that these countries over invest in R&D? The second part of the paper estimated social rates of return to R&D and showed that the returns fall with development. The estimated returns for all countries are high, but our results for the U.S. and the OECD are in the lower bound of existing estimates. Future research could estimate the extent to which R&D-driven patenting activity explains the large returns. Finally, the paper attempted to explain why rich countries invest more in R&D than poor countries, given that the rates of return are higher in the latter. We conclude that financial depth, protection of intellectual property rights, ability to mobilize government resources, and research institution quality are the main reasons why R&D effort rises with the level of development. Finally, the returns to R&D rise net exports of natural resources, resource abundant countries in fact grow faster on average, and the application of R&D is critical to reaping those benefits.

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Figure 1a: R&D/GDP and Development

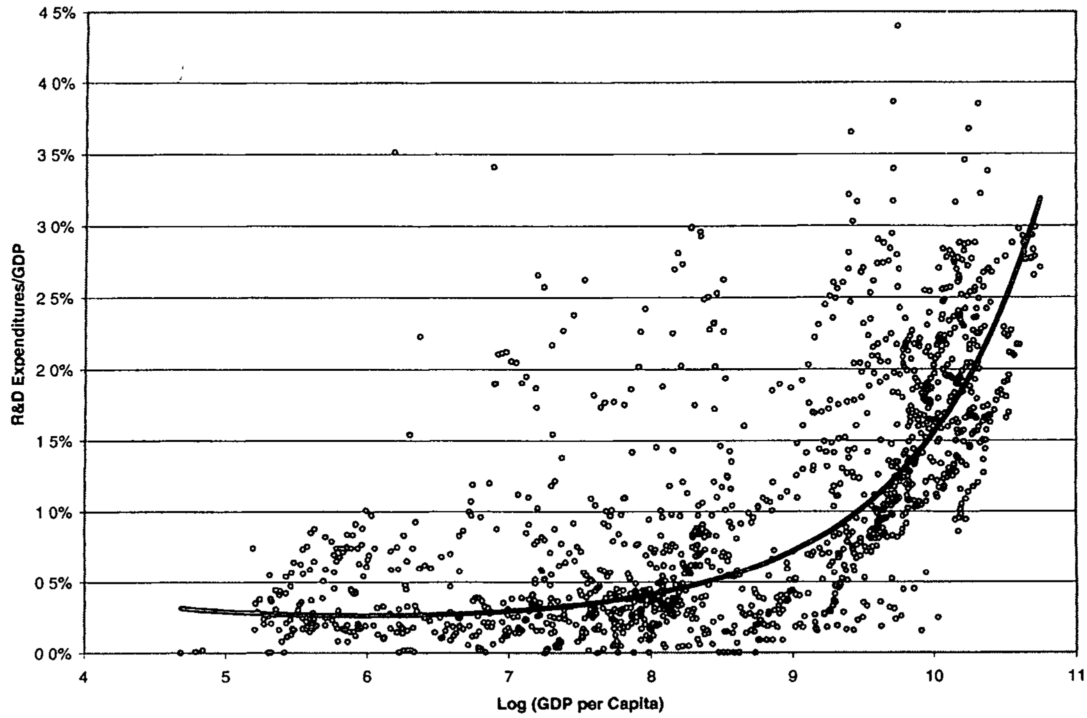
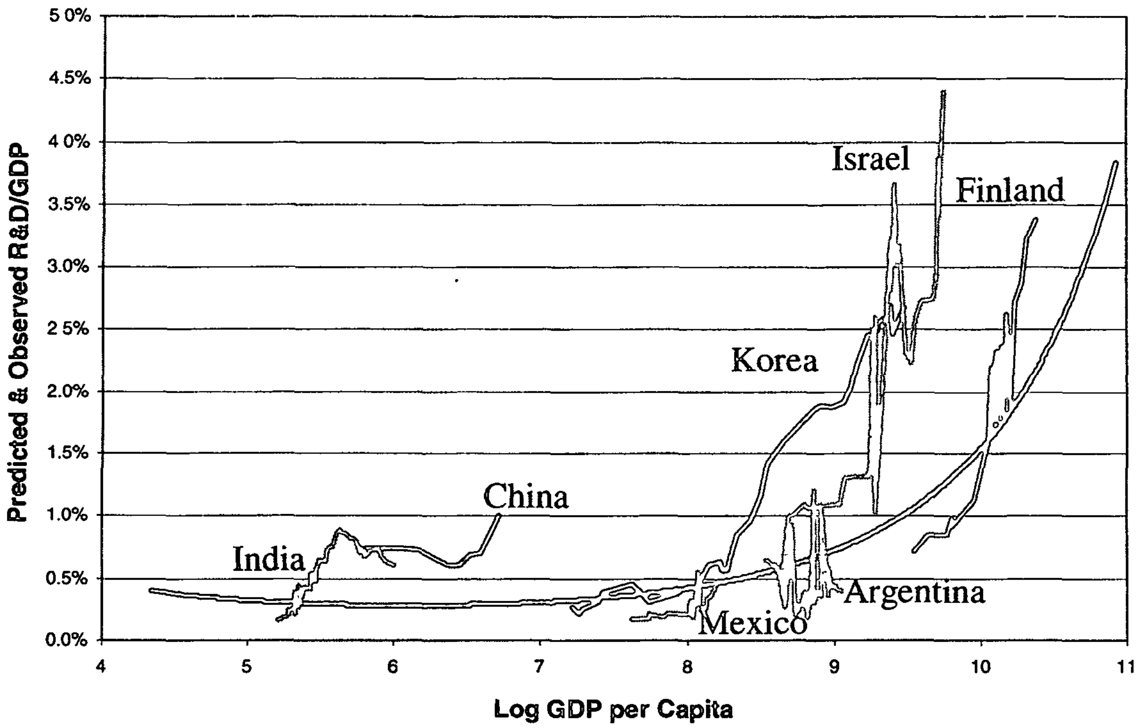
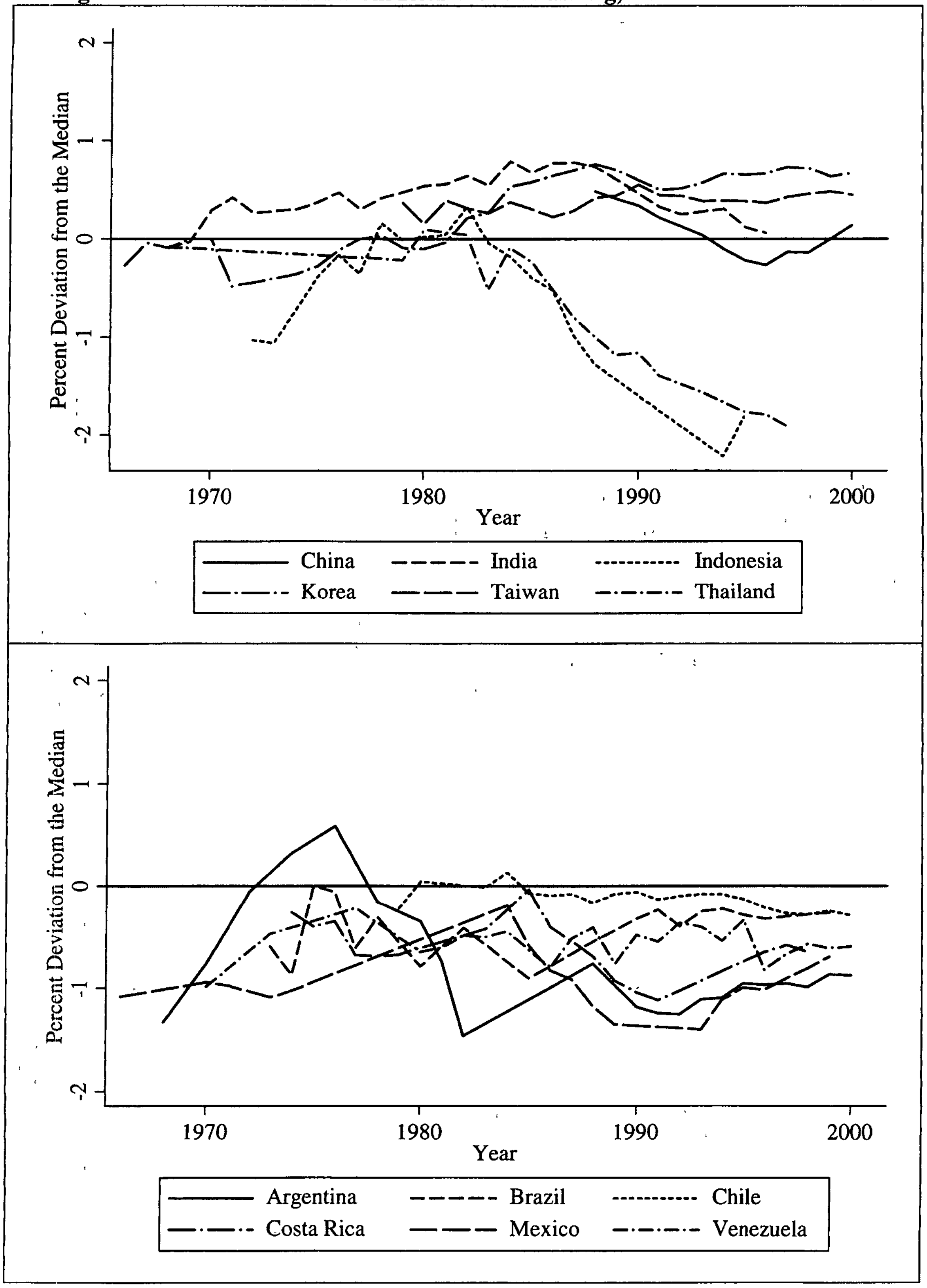


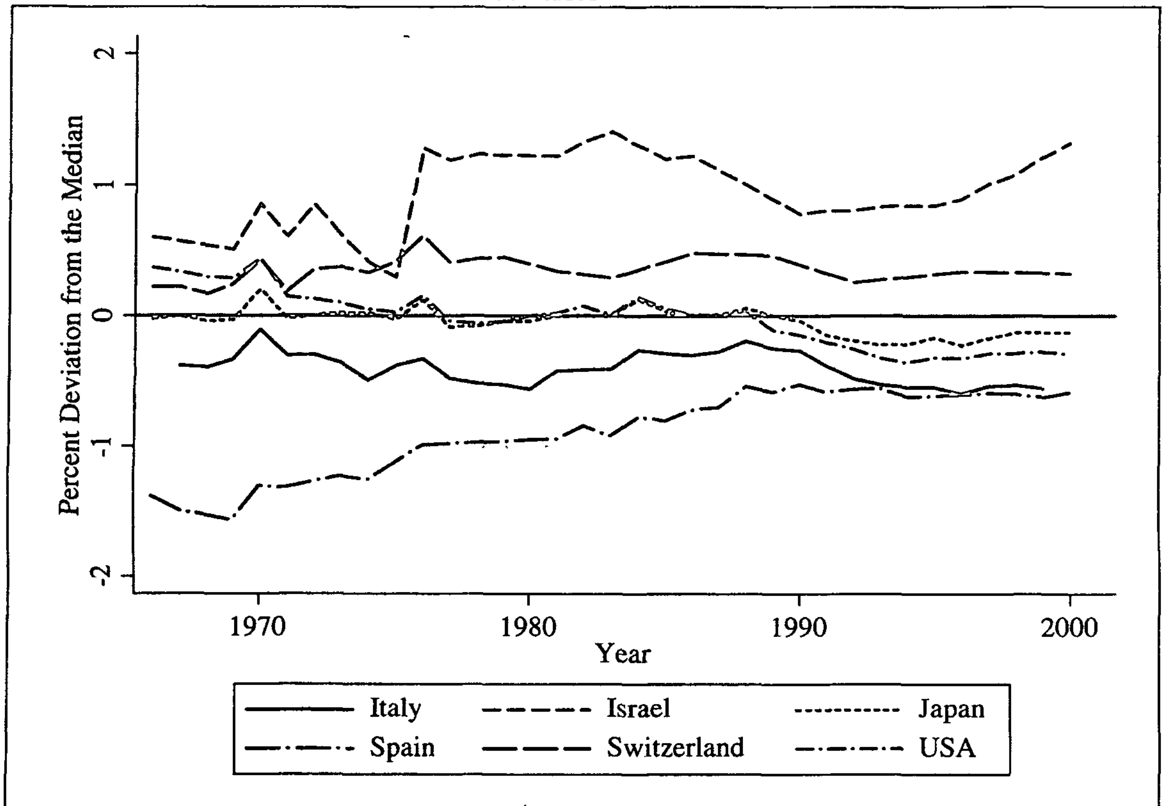
Figure 1b: R&D Over Performers



Figures 2a & b: Residuals from R&D Benchmarking, Asia and Latin America



Figures 2c & d: Residuals from R&D Benchmarking, Advanced Manufacturing and Natural Resource Abundant Countries



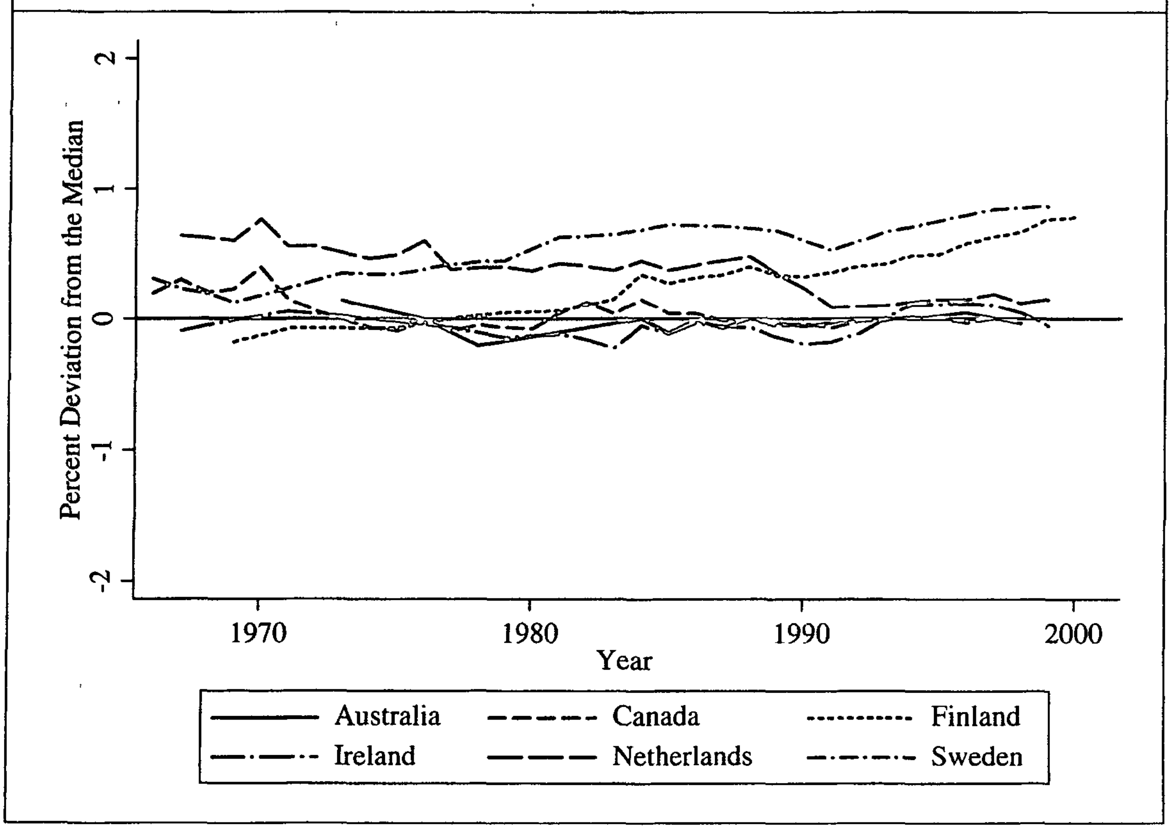


Figure 3. Returns to R&D and the Level of Development

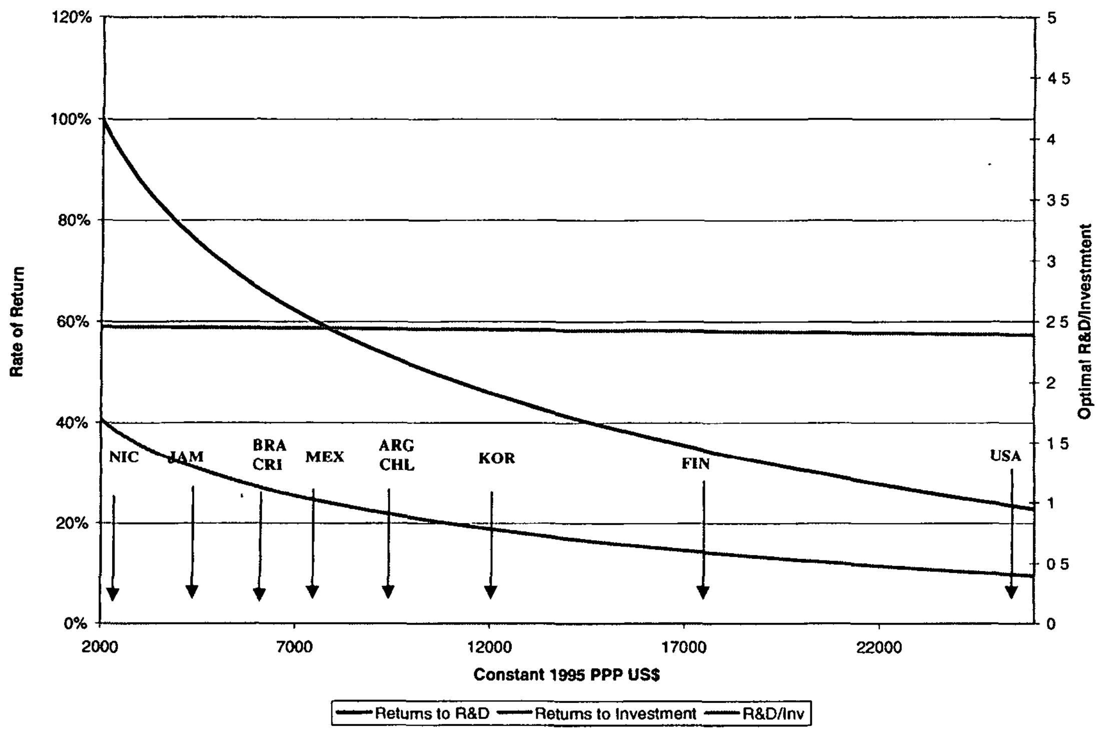


Table1. R&D and Development: Regression Results

	(1)	(2)
Dependent Variable	Log (R&D/GDP)	Log (R&D/GDP)
Estimation Method	Median Reg.	OLS FE
Explanatory Variables:		
Log GDP per capita	-1.30	-1.13
Log GDP per capita squared	0.11	0.11
Over-dispersion test (p-value)	n.a.	n.a.
Adjusted R-squared, Log Likelihood, or Pseudo R-squared	0.32	0.37
F-test of Significance of Fixed-Effects (p-value)	n.a	0.00
Observations	1386	1386
Countries		99

Notes: All coefficients are significant at 99%. N.a. = not applicable.

Table 2. Returns to R&D

Dependent Variable:Growth of GDP (Constant PPP), five year averages 1975-2000.
Methodology: GMM System Estimator

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
Initial level of gdp per capita	0.01	***	0.03	***	0.00		-0.01	**	0.00		0.00		0.09	***
Investment/GDP	0.17	***	1.30	***	0.19	***	0.33	***	0.24	***	0.27	***	0.88	***
Labor growth	0.61	***	0.51	***	0.60	***	0.50	***	0.75	***	0.48	***	0.77	***
R&D/GDP	0.78	***	3.19	***	1.38	***	0.52	***	1.02	***	9.62	***	9.29	***
Tertiary Enrollment ratio							0.06	***	0.03	*	0.05	**	0.02	**
NR-Leamer									0.00	**	-0.01	***	-0 01	***
R&D*(gdp per capita)			-0.30	***							-1.03	***	-0 99	***
R&D*(NR-Leamer)											0.37	***	0.33	***
Investment/GDP*(gdp per capita)			-0.13	***									-0.08	***
Sargan Test(p-value)	0.40		0.33		0.44		0.70		0.37		0.49		0.92	
2nd order serial correlation	0.22		0.23		0.98		0.63		0.72		0.80		0.89	
Observations	162		162		107		107		107		107		107	
Countries	53		53		43		43		43		43		43	

Table 3a. Determinants of R&D: Why Do Rich Countries Spend More?

Dependent Variable: R&D/GDP
Estimation Method: GMM System Estimator

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
R&D/GDP at t-1	0.90 ***	0.86 ***	0.89 ***	0.87 ***	0.90 ***	0.80 ***	0.87 ***	0.96 ***	0.68 ***	0.69 ***
Log (GDPpc)	0.22 ***	0.21 ***	0.22 ***	0.21 ***	0.15 ***	0.00	0.07 *	0.18 ***	-0.02	0.02
GDP growth	-1.22	-0.15	-0.03	0.00	1.12 ***	-0.53	-0	0.09	2.68 **	1.11
Real Interest Rate	-0.45	-0.23 *	-0.40 ***	-0.07	-0.86 ***	-0.04	-0.11	0.52 *	-0.15	-0.49 *
Private Credit/GDP		0.07 ***								0.17
Sd Growth			-0.44 ***							
Log (IP Index)				0.16 ***					0.39 ***	
Gov.Cons./GDP					0.99 ***				1.11 **	1.15 *
Quality of Res. Inst.						1.22 ***			1.12 **	0.98 ***
Collaboration							0.53 ***			
Leamer Index								-1.38 ***		
Sargan Test (p-value)	0.36	0.45	0.52	0.47	0.58	0.42	0.26	0.50	0.96	0.96
2nd Order Serial Correlation (p-value)	0.32	0.35	0.35	0.33	0.33	0.40	0.35	0.47	0.42	0.37
Observations	73	73	73	73	73	73	73	73	73	73
Countries	30	30	30	30	30	30	30	30	30	30

Table 3b. Determinants of R&D: Why Do Rich Countries Spend More?

Dependent Variable: R&D/GDP
Estimation Method: GMM System Estimator

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
R&D/GDP at t-1	0.79 ***	0 65 ***	0.80 ***	0.76 ***	0.74 ***	0.73 ***	0.83 ***	0.75 ***	0.58 ***
Log (GDPpc)	0.40 ***	0.43 ***	0.39 ***	0.23 ***	0.20 ***	0 13 **	0.14 ***	0.46 ***	0.00
GDP growth	2 83 **	3.51 **	1.21	3.25 ***	2.33 ***	2.36 **	3.50 ***	3.98 ***	4.70 ***
Investment/GDP	-0.72	-1.57 ***	-0.55	-1.13 ***	0.11	-0.64 *	-1.25 **	-0.45	-1.14 **
Private Credit/GDP		0.26 ***							0.44 ***
Sd Growth			0.42						
Log (IP Index)				0.29 ***					0.37 ***
Gov.Cons./GDP					3.17 ***				3.35 ***
Quality of Res. Inst.						0.92 ***			
Collaboration							0.47 ***		
Leamer Index								-0.03 ***	
Sargan Test (p-value)	0.1	0.1	0.3	0.45	0.32	0.13	0.16	0.27	0.54
2nd Order Serial Correlation (p-value)	0.47	0.51	0.499	0.53	0.65	0.5	0.43	0.135	0.81
Observations	102	102	102	102	102	101	102	94	102
Countries	41	41	41	41	41	40	41	38	41

Notes: Period dummies were included in all regressions. Coefficients are significant at *** 1%, ** 5%, and * 10%.

Annex. Summary Statistics and List of Countries in the Various Samples.

Table A.1 Variables used in the regressions presented in Table 1

Variable	Mean	Std. Dev.	Min	Max
(1)				
Log GDP per capita	7.77	1.53	4.41	10.94
(2)				
Log GDP per capita	7.78	1.51	4.41	10.94
(3) and (4)				
Log R&D/GDP	-5.05	1.25	-13.25	-3.12
Log GDP per capita	8.51	1.47	4.68	10.75

Table A.2 Variables used in the regressions presented in Table 2

Variable	Mean	Std. Dev.	Min	Max
Growth of GDP	0.02	0.02	-0.03	0.08
Log initial level of GDP per capita	8.89	0.84	6.50	9.95
Investment/GDP	0.23	0.05	0.11	0.41
Labor growth	0.01	0.01	0.00	0.04
R&D/GDP	0.01	0.01	0.00	0.04
Tertiary Enrollment ratio	0.33	0.19	0.02	0.92
NR-Leamer (net exports of natural resources per worker)	0.51	2.18	-2.52	11.11

Table A.3 Variables used in the regressions presented in Table 3

Variable	Mean	Std. Dev.	Min	Max
R&D/GDP	0.01	0.01	0.00	0.04
Log GDP per capita	8.92	0.76	7.03	9.95
GDP growth	0.02	0.02	-0.04	0.08
Fixed Investment/GDP	0.23	0.05	0.13	0.41
Log IP Index	1.01	0.49	-1.11	1.58
Private Credit/GDP	0.73	0.50	0.07	2.08
Government Expenditure/GDP	0.16	0.06	0.07	0.31
Quality of Research Institutions	1.60	0.20	1.06	1.90
Collaboration between productive sector & universities	1.36	0.26	0.60	1.76
Leamer Index	3.66	20.18	-25.23	111.13

TABLE A.4. Complete Sample

ALBANIA
ALGERIA
ARAB EMIRATES
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHRAIN
BARBADOS
BELARUS
BELGIUM
BOLIVIA
BRAZIL
BRUNEI
BULGARIA
CAMEROON
CANADA
CHAD
CHILE
CHINA P.REP.
CHINA,HONG KONG S.A.R.
COLOMBIA
CONGO(DEM. REP)
COSTA RICA
CROATIA
CYPRUS
CZECH REPUBLIC
DENMARK
DOMINICAN REPL.
ECUADOR
EGYPT
EL SALVADOR
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
GUINEA
GUYANA
HAITI
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN
IRELAND
ISRAEL
ITALY
IVORY COAST
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KUWAIT
KYRGYZSTAN
LATVIA
LEBANON
LITHUANIA
LUXEMBOURG
MACAU
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MAURITANIA
MAURITIUS
MEXICO
MOROCCO
NETHERLANDS
NEW GUINEA
NEW ZEALAND
NICARAGUA
NIGERIA
NORWAY
OMAN
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SOUTH KOREA
SPAIN
SRI LANKA
SURINAME
SWAZILAND
SWEDEN
SWITZERLAND
SYRIA
TAIWAN
TANZANIA
THAILAND
THE BAHAMAS
TRINIDAD/TOBAGO
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED KINGDOM
URUGUAY
UZBEKISTAN
VENEZUELA
VIET NAM
YEMEN
YUGOSLAVIA
ZAMBIA
ZIMBABWE

1

TABLE A.5.
Column (1):
53 countries

ARGENTINA*	GUATEMALA	MALTA	SPAIN*
AUSTRALIA*	HUNGARY*	MAURITIUS	SRI LANKA*
AUSTRIA*	ICELAND*	MÉXICO*	SWEDEN*
BRAZIL*	INDIA*	NETHERLANDS*	SWITZERLAND*
CANADA*	INDONESIA*	NEW ZEALAND*	THAILAND*
CHILE*	IRAN	NIGERIA	TOGO*
CHINA P REP.*	IRELAND*	NORWAY*	TURKEY*
COLOMBIA	ISRAEL*	PANAMA*	U.S.A.*
COSTA RICA*	ITALIA*	PERU*	UNITED KINGDOM*
DENMARK*	JAMAICA	PHILIPPINES*	VENEZUELA
EL SALVADOR*	JAPAN*	PORTUGAL*	ZIMBABWE
FINLAND*	JORDAN	ROMANIA*	
FRANCE*	MADAGASCAR*	SINGAPORE*	
GREECE*	MALAYSIA*	SOUTH KOREA*	

*=also used in columns 3-7

TABLE A.6.
41 countries

ARGENTINA	FINLAND*	MEXICO	SRI LANKA
AUSTRALIA*	FRANCE*	NETHERLANDS*	SWEDEN*
AUSTRIA	GREECE*	NORWAY*	SWITZERLAND*
BRAZIL	GUATEMALA	PAKISTAN*	THAÏLAND*
CANADA*	ICELAND	PERU*	TURKEY
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