Why Don't Poor Countries Do R&D?

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Abstract

Using a global panel on research and development (R&D) expenditures, this paper documents that on average poor countries do far less R&D than rich as a share of GDP. This is arguably counter intuitive since the gains from doing the R&D required for technological catch up are thought to be very high and Griffith et al (2004) have documented that in the OECD returns increase dramatically with distance from the frontier. Exploiting recent advances in instrumental variables in a varying coefficient context we find that the rates of return follow an inverted U: they rise with distance to the frontier and then fall thereafter, potentially turning

negative for the poorest countries. The findings are consistent with the importance of factors complementary to R&D, such as education, the quality of scientific infrastructure and the overall functioning of the national innovation system, and the quality of the private sector, which become increasingly weak with distance from the frontier and the absence of which can offset the catch up effect. China's and India's explosive growth in R&D investment trajectories in spite of expected low returns may be justified by their importing the complementary factors in the form of multinational corporations who do most of the patentable research.

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1 Introduction

The existing literature suggests that developing countries should invest very heavily in research and development (R&D). The estimates of the return to Research and Development expenditure (R&D) for advanced countries have been argued to be so high as to justify levels of investment multiples of those actually found (Jones and Williams, 1998).¹ The case is arguably even stronger for poor countries where a long literature argues that R&D is essential to the “absorptive” or “national learning” capacity required to exploit technological advance in the advanced countries.² Empirically, Griffith et al. (2004) for the OECD demonstrate that the estimated returns to R&D, in fact, rise with distance from the technological frontier and increasingly reflect the greater gains from catch-up afforded to follower countries. Extrapolating their estimates out of sample to even middle income countries, the implied returns are truly large and suggest a much larger effort in R&D is justified in developing countries than found in the advanced.

Yet Figure 1 establishes that the poor countries invest far less as a share of their GDP than rich countries in R&D: the Scandinavian countries, Japan and the US occupy the top,

¹See Hall et al. (2010) for a recent and very complete tabulation of studies of the returns to R&D (see also Sveikauskas (2007)). In this article, we will focus mostly on those of the last 20 years. Jones and Williams (1998) argue for the US that the ratio of the optimal level of R&D to actual equals the ratio of the social rate of return to R&D to the long run interest rate. They estimate this to be 28%, a modest estimate along Hall et al. (2010)’s spectrum of estimated returns, and, given the long run real US interest rate of 7%, they argue that the US should be investing perhaps 4 times the present R&D level observed which averaged approximately 2.6% of GDP during 1995-2000. Relatively few 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; Potterie and Lichtenberg (2001) find returns of 68% in the G7 and 15% for a subset of the remaining OECD countries. Kao et al. (1999) for 22 OECD countries plus Israel find returns of 120% for the G7 and 79% for the remainder. A previous incarnation of this paper, Lederman et al. (2003) used an earlier version of the data base here and generated results in the same vicinity.

²Cohen and Levinthal (1989), Griffith et al. (2004) among others stress learning -knowing where the frontier is and figuring out what adaptations are necessary- as the “second face” of R&D. See also Forbes and Wield (2000); Pavitt (2001); Baumol et al. (1994); Nelson and Phelps (1966); Foster and Rosenzweig (1996); Cohen and Levinthal (1989); Benhabib and Spiegel (1994, 2005); Basu and Weil (1998); Acemoglu and Zilibotti (2001); Howitt (2000); Aghion et al. (2005); Howitt and Mayer-Foulkes (2005). Pavitt (2001) argues that even 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.

Africa and Asia the bottom. The literature offers various possible explanations. Griffith et al. (2004) postulate the wedge between private and social returns; Aghion et al. (2010), Bond et al. (2010), Hall and Lerner (2009), Mulkay et al. (2000) have explored the role of credit constraints; Bloom (2007), the depressing impact of uncertainty, all of which would arguably be more binding in LDCs. However, this still raises the question of why, given these high rates of return, developing countries do not take measures to offset the implicit market failures in credit, appropriability, or insurance and facilitate private sector R&D investment, or even undertake it directly. In fact, to re-frame Lucas' famous observation about growth, confronted with the rates of return found in the literature, it would be hard for governments to think of anything else. Indeed, looking again at figure 2, the dramatic trajectories of two important exceptions, China and India (following Israel, Finland, Korea previously), suggest that they, in fact, think about it a lot.

However, this paper argues that developing country governments may well be rational: there may be countervailing forces that prevent Griffith et al. (2004)'s tendency from continuing monotonically with distance from the technological frontier. In particular, another literature stresses the necessary complementarities to R&D expenditure which are likely to diminish with distance from the frontier and hence reduce the efficacy of a given unit of R&D.³ Howitt (2000); Aghion et al. (2005); Howitt and Mayer-Foulkes (2005) for example, postulate a simple parameter on efficacy of R&D that could capture any number of institutional, and educational factors which can offset the Schumpeter catch-up effect.⁴ In particular, analogous to (Lucas, 1988)'s classic argument for the complementarity of human and physical capital, a large literature sees education broadly construed as a necessary complement, especially for technological diffusion (Benhabib and Spiegel, 1994; Caselli, 2001; Klenow and Rodriguez-Clare, 2005; Benhabib and Spiegel, 2005; Howitt and Mayer-Foulkes,

³More generally, recent literatures have stressed the very large impact that missing complementarities can have in stymieing development (see Kremer (1993); Jones (2011))

⁴Aw et al. (2008) argue from Taiwanese data that a larger export market increases the expected returns to R&D. To the degree that poorer countries have smaller markets and fewer export linkages, the returns may be lower.

2005). Basu and Weil (1998); Acemoglu and Zilibotti (2001) argue that technical advances at the frontier may not easily translate to advances for developing country because of different technologies presently applied, or skills mismatch. Rosenberg (2000) and Nelson (2005) discuss the overall system of universities, private sector research departments, and higher level of human capital which evolves with development and which, in the end, is what actually does quality R&D.

Numerous authors have suggested the importance of learning by doing and the quality of the private sector as critical elements of innovation (Lucas (1988); Aghion et al. (1998); Young (1993)).⁵ To the degree that poorer countries have less sophisticated firms, or simply less accumulated experience, the quality of this feedback diminishes. Young (1992) argues that Singapore's targeting policies drove the economy ahead of its accumulated learning by doing and hence into the production of goods in which it had lower and lower productivity, leading to low TFP growth. Relatedly, the entrepreneurial skills studied by Baumol (1990); Murphy et al. (1991); Acemoglu et al. (2006) are necessary to translate R&D into market returns, and Bloom and Van Reenen (2007) show the ability to manage new technologies decreases with distance from the frontier.

Other proposed facilitators of technological transfer which would affect the return to R&D include human interactions across geographical space (Comin et al., 2012), trade (Eaton and Kortum, 1999, 2001; Caselli, 2001; Keller, 2004; Comin and Hobijn, 2004)), adoption of predecessor technologies (Comin et al., 2010; Comin and Hobijn, 2004), political barriers (Parente and Prescott, 1994; Caselli, 2001; Comin and Hobijn, 2009), all of which plausibly worsen with distance from the frontier.

Demonstrating the salience of any particular complement is challenging, even at a micro

⁵Aghion et al. (1998) argue that "Fundamental and secondary research are complementary activities; in order to exploit fully the fundamental knowledge generated by R&D, a firm must put that knowledge into practice and resolve the unexpected problems and opportunities that only experience can reveal" p.174.

economic level see (Mohnen and Roller, 2005). At the macro economic level, as we move from the frontier, many things move concomitantly, and it becomes even more difficult. That said, as an example figures 3 and 4 plot the perceived quality of scientific research institutions, and the degree of University-Industry collaboration against distance to the technological frontier and suggest that such factors are plausibly relevant (World Economic Forum et al., 2012). The former is consistent with more general arguments about human capital above. The lack of collaboration could result from the perceived low quality of research, or could reflect the lack of sophistication of the private sector- it does not recognize such alliances as productivity enhancing. Both the effective output of R&D per dollar spent, and the likelihood that it will be communicated to the private sector fall among poorer countries suggesting an important offset to the Schumpeterian benefit to lagging.

In this paper, we estimate the pattern of returns to R&D across the development process as suggestive evidence that such offsetting effects may be important. We construct a global panel of R&D expenditure across 40 years for 75 countries that allows us to treat a broader sample of rich and poor countries than has heretofore been done. To date, the literature taking a global view on returns to R&D is relatively thin and we first estimate a large and statistically significant rate of return from our sample comparable to those found in earlier studies.⁶ Experimenting with internal and external instruments to control for the possible endogeneity of R&D still leaves lower, although still high rates of return.

We then employ recent advances in Instrumental Variable Varying Coefficient (IVVC) estimators to allow returns across all factors to vary semi-parametrically across the development space. There is increasing dissatisfaction in the growth literature conceptually about the assumption of a constancy of parameters across countries (see Pack, 1994; Brock and

⁶Lichtenberg (1993) works with panel of 57 countries with between 1 and 15 annual observations and finds that the social return to privately funded R&D is on the order of seven times as high as the return to fixed investment. He does not, however, attempt to identify a difference in rates of return between the developing countries and advanced countries in his sample. Coe et al. (1997) and a sub-sequent literature (Keller, 2002) estimate the impact of foreign R&D on manufacturing TFP growth in developing countries, abstracting from local R&D efforts which are assumed minor.

Durlauf, 2000). Clearly, Griffith et al. (2004), drawing on Aghion and Howitt (1992); Aghion et al. (1998) offer one example in arguing that $r_{R\&D} = \rho + \delta_2 \ln(A^*/A)_{-1}$ where A , A^* are TFP and TFP at the frontier respectively, the second term arising from the additional effect of R&D as facilitating technological transfer from the frontier to the follower country. More generally, the complementarities among productive factors may not occur at the same intensity in frontier and developing countries (due to institutional barriers, lack of education, multiple externalities and non-convexities reflected in evident market imperfections, etc.). Azariadis and Drazen (1990) suggest that countries that are identical in their structural characteristics but differ in initial conditions may cluster around different steady state equilibria in the presence of increasing returns to scale from some factor of production, market imperfections, non-convexities in the production function, etc. (Galor, 1996; Howitt and Mayer-Foulkes, 2002).

From the purely statistical point of view, Kourtellos (2002) notes that numerous studies show evidence of misspecification (generally in the form of nonlinearities) and suggest that the assumption of a single linear model when applied to all countries is invalid (see Durlauf and Johnson, 1995; Durlauf et al., 2001; Hansen, 2000; Liu and Stengos, 1999; Desdoigts, 1999; Kourtellos, 2001). In our case, we want to allow the return to R&D to vary, but we also want to ensure that we are really picking up variation in returns to R&D and not the result of excessive constraints on the other potentially variant parameter values. Hence, we follow recent work by Hastie and Tibshirani (1993) and Fan and Zhang (1999, 2000) that allows the full parameter vector to vary and Cai et al. (2006) who extend the methodology to accommodate endogeneity in the conditioning set.⁷

⁷The suggested approach to specify the determinants of economic growth dates back to Mansfield (1965) and Griliches (1986). As Jones and Williams (1998) note, most of the literature aimed at estimating returns in this tradition is based on neoclassical growth models in which R&D is simply an alternative form of capital investment. Such an approach ignores many of the distortions associated with research that are formalized by the new growth theory, including monopoly pricing, inter temporal knowledge spillovers, congestion externalities and creative destruction. We take advantage of this in the sense that while the differentiated effect among creators and absorbers, in part induced by the creative destruction process, is not captured by any argument in the last equation, it is reflected in the varying estimates of the contribution of R&D to growth. This variation is shown to depend on the degree of economic development which in turn is related to the clustering of originators and imitators of technological progress.

We reject constancy of returns across the development process. We confirm Griffith et al. (2004)'s findings of increasing returns with distance from the frontier. However, the effect is not monotonic across the entire development process- returns follow an inverted U shape. For countries further from the frontier than, for instance, modern day Mexico, the returns fall off and then eventually become negative. These results are robust to different specifications using net or gross R&D investments, using internal and external instruments, using direct and indirect measures of TFP and doing a quality adjustment to the labor factor. Finally, we offer an explanation for why China and India are investing so much in R&D if, for countries of their level of development, the likely returns are small.

2 Returns to R&D and Distance from the Technological Frontier

We begin following the broadly standard approach to estimating the returns to R&D. As in Jones and Williams (1998) we begin from a simple production function where

$$Y = F(A, K, L) \tag{1}$$

where output Y is produced as a function of ideas or knowledge capital and a collection of factors, in our case labor and physical capital. As an approximation

$$\Delta \ln Y = \alpha + \beta_A \Delta \ln A + \beta_K \Delta \ln K + \beta_L \Delta \ln L + \epsilon \tag{2}$$

We employ the common transformation

$$\beta_f \Delta \ln F = r_f \frac{F}{Y}$$

where r_f is the rate of return on factor F and $\frac{F}{Y}$ is the share of investment F in output for both physical and knowledge capital but leave labor in growth terms. We can now write the equation as

$$y = \gamma X + \epsilon \quad (3)$$

where y is the growth rate⁸ and X includes the growth rate of labor, the respective shares in GDP of physical and knowledge capital, and lagged GDP to capture any convergence effects not captured in the movement of included factors of production.

Jones and Williams (1998) and Griffith et al. (2004) among others impose standard parameter values on labor and capital thereby transforming y into the log difference of TFP. The advantage of this specification is that the generated TFP measures can be used as the distance to the frontier measure that most corresponds to that envisaged by theory. The disadvantage is that it also *a priori* rules out any interaction in the estimation between R&D and the other observed and unobserved factors of production by fixing their marginal productivity to a constant for all levels of development. Hence, the imposed return to physical capital may actually be capturing part of (or not capturing enough of) the return to R&D.

We follow recent work by Hastie and Tibshirani (1993) and Fan and Zhang (1999, 2000) that allows the full parameter vector to vary in a functional coefficient representation, and Cai et al. (2006) who extend the methodology to accommodate endogeneity in the conditioning set. The functional approach differs from, for instance, locally weighted regression (see Cleveland and Devlin (1988)) which uses moving weighted subsets of the data to describe the parameter surface. Rather, the functional approach explicitly models the parameter space at each point as a function of some inducing variable, in our case, distance to the frontier. It uses all the data to estimate the function at each point, although weighting observations close to each point more heavily than those further away. Equation (3) generalized in this

⁸Measured as the log difference between quinquennia of real GDP for each country.

framework becomes:

$$\begin{aligned} y &= \gamma(U)X + \epsilon = \sum_{j=1}^p \gamma_j(U)X_j + \epsilon \\ E(\epsilon|U, X) &= 0 \end{aligned} \quad (4)$$

where U is the inducing variable of the P dimensional functional coefficient $\gamma(U)$. If a random sample $\{U_i, X_i\}_{i=1}^n$, where the subscript i refers to a country-period observation, is drawn from a distribution $F_{U,X}$, then for each given point u_0 , the function $\gamma_j(U)$ can be approximated locally as a q degree Taylor expansion as:

$$\gamma_j(U) \approx \sum_{l=0}^q c_{jl} (U - u_0)^l \quad (5)$$

for sampling points U in a neighborhood of u_0 . This results in the following locally weighted least squares problem:

$$\underset{c_{j,l}}{\text{minimize}} \sum_{i=1}^n \left[y_i - \sum_{j=1}^p \sum_{l=0}^q c_{jl} (U - u_0)^l X_{ij} \right]^2 K_h(U_i - u_0) \quad (6)$$

$K_h(\cdot) = (1/h)K(\cdot/h)$ and $K(\cdot)$ is the Epanechnikov kernel $K(U) = (3/4)(1 - U^2)I(|U| \leq 1)$ which weights observations further from μ_0 progressively less and determines the smoothness of the estimated $\gamma(U)$ with h as the bandwidth. This is the approach used by Durlauf et al. (2001); Kourtellos (2002) to estimate their Local Solow Growth Model.

Cai et al. (2006) extend the approach to the case where some elements of X cannot be taken as exogenous:

$$\begin{aligned} y &= \gamma(U)X(Z_1) + \epsilon \\ E(\epsilon|\mathfrak{S}) &= 0 \end{aligned} \quad (7)$$

where $\mathfrak{S}$ is a matrix consisting of a matrix Z_1 of m exogenous variables and a matrix Z_2 of l

excluded instrumental variables. The reduced form becomes:

$$E(Y|\mathfrak{S}) = \sum_{j=0}^p \gamma_j(U) E(X_j|\mathfrak{S}) = \sum_{j=0}^p \gamma_j(U) \pi_j(\mathfrak{S}) = \gamma(U) \Pi(\mathfrak{S}) \quad (8)$$

where $\gamma(U)$ is a vector of functional coefficients of the instrumented variables from the first stage, $\Pi(\mathfrak{S})$. If a random sample $\{U_i, X_i, Z_{2i}\}_{i=1}^n$ is drawn from a distribution F_{U,X,Z_2} , then for each given point u_0 and by analogy to equation 5 above, the second stage estimates of $\gamma(U)$ can be generated by a locally weighted regression of y on $\hat{\Pi}(\mathfrak{S})$

$$\underset{b_j, c_j}{\text{minimize}} \sum_{i=1}^n \left[y_i - \sum_{j=1}^p \{b_j + c_j(U_i - u_0)\} \hat{\pi}_{j,-i} \right]^2 K_{h_2}(U_i - u_0) \quad (9)$$

Cai et al. (2006) find that a first order approximation, in this case $b_j + c_j(U_i - u_0)$ is sufficient to generate efficient estimates. The estimates of $\pi_j(\mathfrak{S})$ are generated in the first stage by a locally weighted regression of X on $\mathfrak{S}$ under jackknife sampling on i :

$$\underset{\alpha_{i,j}, \beta_{i,j}}{\text{minimize}} \sum_{k \neq i}^n \left[X_{kj} - \alpha_{ij} - (\mathfrak{S}_k - \mathfrak{S}_i)' \beta_{ij} \right]^2 K_{h_1}(\mathfrak{S}_k - \mathfrak{S}_i)$$

The calculation of the corresponding variance-covariance matrix is described in Cai et al. (2006).

3 Data

We use an unbalanced panel of 75 countries covering the period 1960 - 2000. The data set comprises a number of variables coming from different sources. Income, Investment, and Labor growth are drawn from Penn World Tables. The educational data from Barro and Lee.

3.1 R&D

The R&D series from 1960-2000 extend the compilations by Lederman and Saenz (2005) which use national surveys that use a common definition of expenditures that includes fundamental and applied research as well as experimental development. In line with our discussion of the dual role of R&D the category considers not only the traditional investments for development of new technologies expected in advanced countries, but also investments in the adoption and adaptation of existing technologies more likely to be labeled as R&D into developing countries. The series are constructed combining data published by UNESCO, the OECD, the Ibero American Science and Technology Indicators Network (RICYT) and the Taiwan Statistical Data Book, following the definitions convened in the OECD Frascati Manual.

Though it would be desirable to study the evolution and rate of return 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, but rather into productive and non-productive sectors, the latter accounting for roughly 20% of the total. 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 public utilities or other state owned enterprises, focusing on this breakdown is less interesting than the public/private sector split would be.

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 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 a primary focus of this paper, we want to include as many as possible.

Griffith et al. (2004) assume a negligible rate of depreciation, and Jones and Williams (1998) assume a zero depreciation rate, partly on the grounds that existing studies suggest the best fit occurs without adjustment. Hall (2010) suggests that identifying the appropriate level of depreciation is extremely difficult and sensitive to method of estimation. However, Hall and Mairesse in their work on French and the US firms construct stocks of physical and R&D capital through a perpetual inventory method rather than looking at investment rates and we check to see if our results are robust to both the gross (undepreciated) R&D as well as depreciated (net) series.

3.2 Instruments

The reported returns to R&D in the advanced countries are high and a range of authors (see Griliches, 1987; Barro and Sala-i Martin, 2003; Hall and Mairesse, 1995; Hall and Jones, 1999) argue that the estimates may be biased, perhaps due to R&D's endogeneity arising from liquidity constraints, or joint output and investment decisions. Finding suitable instruments has proven problematic. Griffith et al. (2004, 2006) at the sector level correctly report the absence of papers that have found reliable external instruments and rely largely on internal instruments.⁹ While the weak exogeneity of lagged R&D in particular can be questioned, the literature provides apparently successful examples of their use. For example, Hall and Mairesse (1995), comparing France and the US sequentially test the admissibility of instruments beginning with a three year lag and working toward the contemporaneous values. They find lag 0+ instruments admissible for France and 1+ for the US. Were this generalizable, this suggests that our first approach, instrumenting our investment variables using two lags, or the values of 10 years prior, is plausibly long enough to guarantee weak exogeneity.

⁹Griffith et al. (2006) use the System GMM estimator as one option. We also do this. We find that the GMM parameter for gross RD to be roughly 60% of that of the FE with internal lags, while the net parameter is 80%. Since the instrumented FE is the closest to the IVVC, we report only those results.

We also explore using the evolution of intellectual property rights protection (IPRs) as an external instrument. This quinquennial index of property rights protection encompasses five components measuring each country's IPR laws coverage and enforcement in an updated version of Ginarte and Park (1997).¹⁰ This instrument is attractive since the channel through which it is most likely to affect growth is precisely through innovation effort—stronger IPRs allow investors to appropriate more of the unrealized returns to R&D, and because numerous studies have taken IPRs to be exogenous (see Deolalikar and Röller (1989); Lach (1995); Thompson and Rushing (1996, 1999); Maskus and McDaniel (1999); Crosby (2000)). This is most likely the case for the developing countries, since the variation of the index appears largely driven by pressure from the United States, Europe and Japan in the context of trade rounds where protection of IPRs has, in fact, not been driven by a perception of their benefit per se for developing countries, but rather as a price to pay for greater access to advanced country markets.¹¹ In this case, one important channel of endogeneity, that of the feedback from future expectations of growth to R&D, or even the joint decision of output and R&D are likely to be mitigated. That said, clearly the correlation with trade agreements potentially opens an alternate channel to growth through expanding trade. We control for this as well and it appears not to be the case (See diagnostics in Annex II). Clearly, the argument that IPR regimes have been largely driven by trade agreements is more likely the case in poorer countries than richer countries and we show that our central results holds for this particular group of countries.

¹⁰We are grateful to Walter Park who kindly shared the updated version of his original indicator (Park, 2001, 2008). The components are the coverage of patent laws across seven industries, membership in three key international patent agreements, provisions for loss of rights for loss of protection, three types of enforcement mechanisms, and the duration of patents relative to international standards. The composite index ranges between zero and five with higher values indicating stronger IPR protections and enforcement.

¹¹In 1986, the US, Japan and Europe successfully introduced IPRs in the Uruguay Round in Punta del Este as the Trade Related Aspects of Intellectual Property Rights (TRIPS). As Maskus describes, the TRIPS accord was fashioned against a backdrop of aggressive diplomatic efforts by the US to increase IPRS in Korea (and Taiwan) in the 1980s, and language governing IPRs would increasingly appear in trade agreements such as NAFTA. Dani Rodrik, making Maskus' point to an even more pessimistic extreme, also sees the IPR regime as coming out of negotiations in the WTO context and argues they are "utterly devoid of any economic rationale beyond the mercantilist interests of a narrow set of powerful groups in the advanced industrial countries. The developmental pay-off of most of these requirements is hard to see" (Rodrik (2001), P 27).

4 Results

4.1 Parametric Benchmark

We first report quinquennial averages of the most important variables involved in the analysis, for OECD and non-OECD countries. Table 1 shows the evolution of annual economic growth rates, educational attainment, openness to trade and IPR. Figure 5 plots the densities of three of the key variables against distance to the technological frontier. The first sub-panel approximates table 1 in showing that level of R&D spending decreases with distance from the frontier, but also shows that the vast majority of countries are found fairly distant with fairly few wealthy countries at very high levels. Education, shows a broadly similar slope although, in this case, the majority of observations are found among rich countries with high levels of education. A broadly similar pattern emerges with IPRs.

We begin estimating equation (3) with imposed fixed parameters. All the variables are demeaned within countries to remove country fixed effects and all the non-dichotomous explanatory variables are expressed as quinquennium averages. Tables 2 reports the parametric estimates. Each panel reports the OLS and fixed effect estimates with three specifications: the first without instruments, the second employing internal instruments, and the third, the external instrument. The fixed effect specification is closest to the IVVP estimator. A number of finding merit note.

The returns of physical investment prove to be quite robust to all of our specifications hovering between 0.2 to .273. Labor growth, however, proves less stable, falling in both magnitude and significance in the fixed effects specifications to around .2. In the FE estimators, initial GDP enters persistently significantly between -.041 and -.05.

In all but 4 of the 12 specifications, R&D emerges as significant and returns to gross R&D

vary between .25 and 1.1. These figures are in line with those found by much of the literature (see, for example Coe and Helpman (1995)). Across all specifications, as in Hall and Mairesse (1995) and Griliches and Lichtenberg (1984) the point estimate on R&D rises by non-trivial magnitude, often double, when we use net R&D rather than the gross. Clearly, the choice of depreciation rate is critical to the measured rate of return what is important for this study is that for a common rate we find the significance of R&D remains and second, that the patterns generated by the IVVP results are not sensitive to depreciation issues. Both are true.

Critically, instrumenting yields significant variation in R&D. For instance, in the gross FE regression, R&D falls from .74 to .5 using internal instruments, but loses value and significance completely with the external. Both findings suggest that the instruments are plausibly capturing endogeneity of important magnitude. One interpretation is that once well-instrumented, R&D has a vastly reduced impact on growth. However, in what follows, we argue that the poor results are partly due to constraining the parameters to be constant across the development process.

4.2 Varying Coefficients

Figure 6a shows the evolution of the VC coefficients related to Investment in Physical Capital, Labor Growth and Initial Output when mapped against the distance to the economic frontier as measured by relative GDP in each quinquennium. The three horizontal lines crossing each graph correspond to the FE estimates bracketed by the 95% confidence interval. In general, the effective reduction in observations at any point, and the asymmetry in the estimation as we approach the “edges” leads to larger standard errors and less reliable coefficient estimates at the extremes. That said, the graphs are overall consistent with the parametric estimates: from Table 2, the FE without IV estimates are roughly .27 on physical capital, an (insignificant) coefficient of .24 on labor growth and negative -.05 on initial GDP.

Further, these three coefficients show a reasonable degree of stability across the spectrum

of distances from the frontier, albeit with important exceptions. Physical investment arguably shows a downward trend. The values at DF (Distance from the Frontier) -3.5, corresponding to modern Ecuador, Egypt, Bolivia and China, are higher and outside the confidence interval of the estimates at DF -2.0 (modern Mexico, Venezuela, Chile, Hungary, Malaysia) and the coefficients for the most advanced countries fall off as well.¹² This may be consistent with, for instance, Oulton and Young (1996) who present evidence that the importance of investment in physical capital falls as countries grow richer.

Labor growth shows a substantial reduction in standard errors and increases in value as we approach the advanced countries. At DF -5, corresponding to modern Great Britain and Austria, the impact of labor growth appears to rise from close to zero to 1. We will explore the possibility that this is due to higher quality of labor below.

Initial output varies in impact. there appears to be a significantly stronger convergence effect for countries between DF -1.5, corresponding roughly to modern Argentina, Greece, and DF-3.0 corresponding roughly to modern day Romania, El Salvador, Tunisia. At both extremes, although particularly among the more developed countries, the coefficient drifts outside the confidence interval of this group suggesting that the difference is statically significant. The convergence effect appears less powerful among the richer and poorer countries, a fact that we will return to later.

The top panel of Figure 6b presents the corresponding trajectory of the coefficient on gross R&D. The returns to investment in R&D are emphatically less constant. In the first, uninstrumented panel, the estimates cross the confidence interval from the fixed parameter estimates more than once and drift outside of the confidence intervals in other ranges. Broadly, we can delimit three regions according to the distance to the economic frontier: Advanced countries, with observations lying to the right of DF -1.2 (modern New Zealand,

¹²Although Functional estimation should be less affected by boundary effects, there appears to be some loss of estimate quality as we near the edges of the data along U.

Korea and Spain), show rates of return around .10 - .20. Consistent with Griffith et al. (2004) there is also a rise moving away from the frontier the slope of which increases sharply at DF -1.5 (Argentina, Greece) and then peaks at DF -2.0 (modern Mexico, Venezuela, Chile, Hungary, Malaysia) with a value above 2.0. Moving further away from the frontier, the returns fall monotonically again reaching, around DF -3.0 (modern Romania, El Salvador, Tunisia) point estimates below zero, although not significantly so. It is clearly the case that the coefficient in the intermediate zone of -3 to -1.5 drifts outside the confidence interval of the other two segments, suggesting a substantial break in the returns to R&D.

We repeat the exercise with the net measure of R&D investment and find similar patterns and hence, we do not report them. In the next two sections, we attempt to improve the gross estimates, first, through exploring internal and external instruments, and second investigating the role of education (and hence, labor quality) in the patterns observed.

4.3 Instrumental Variables Varying Coefficients

The bottom two panels of Figure 6b shows the evolution of the IVVC when lagged R&D Investments and IPR regime are used as respectively internal and external instruments for R&D. The internal instrument estimates of the coefficient on R&D show a less consistent story although the slight upward slope from DF -.05 to -1.5 remains, and there is also a large jump in returns as before, however this time the sharp increase appears more around DF -2.5 instead of -1.5. Again, the returns go negative below DF -3.5.

The estimates with external instruments broadly follow the trajectory of the non-instrumented estimates, albeit of smaller magnitude consistent with the parametric results: the same slight increase from DF 0 to -1.5 as found without instruments and then, again a peak around DF -2 and then a fall again to be negative, and significantly so, around DF -3.0. The standard errors are smaller making rejection of parameter constancy even more convincing. The very significant value around the middle income

countries suggests that although the FE parametric estimates were small and insignificant, this is more an artifact of constraining the coefficients to be constant over development levels.

For a greater clarity, Figure 7 repeats our earlier exercise with the uninstrumented results, taking the external instruments specification and assigning to representative points a country/period combinations. The estimates do not correspond to those countries, they merely serve as representative markers of distance from the frontier. Our results are broadly consistent in magnitude with those recent in the literature. The span of countries approaching the frontier (but before the graph turns negative) show returns of around 30%. This is broadly consistent with the OECD literature (See Hall et al. (2010) for a review of the literature over the last quarter century) although substantially below other studies using cross country data which find much higher returns for the G7 (see for example Coe and Helpman (1995); Potterie and Lichtenberg (2001); Kao et al. (1999)). Most recently, and of very similar magnitude to our estimations, Doraszelski and Jaumandreu (2013) for instance, find an average rate of 40% for Spain (1996-2000).

Overall, we also confirm Griffith et al. (2004)'s finding of an incline in returns leaving the frontier and, again, of broadly similar levels of magnitude. The highest rates of return appear accrue to countries of a level of distance from the frontier corresponding to "modern day" (1996-2000) Brazil, Chile, Hungary, Mexico, Poland and Venezuela with rates perhaps 2 times those found by Griffith et al. (2004). Returns then fall to 30-50% of the peak for Thailand, Peru and Romania, and would probably be negative for countries at Ecuador, Egypt, Indonesia and China's income. The higher returns for middle income countries are consistent with the stronger convergence force found above for the same countries. To the degree that convergence is driven by technological adoption, these countries potentially are gaining both through both R&D and non-R&D related channels.

As discussed above, the external instrument is likely to be more defensibly weakly

exogenous for the sample of poorer countries whose changes in IPR regime are more exogenously induced. We rerun the exercise using just countries whose distance from the frontier are below those of Mexico in 1996-2000 and the results doing this yield patterns very similar the left side of the graphs above with declining returns with distance from the frontier.

4.4 Controlling for labor quality

One explanation for the upward trend in the coefficient on labor, particularly as we near the frontier, is that the quality of labor is increasing across level of development. This suggests the potential importance of incorporating education into the analysis. We create an augmented labor variable by controlling for years of education, drawn from Barro and Lee (2001). We then follow Caselli (2005), who in the tradition of Hall and Jones (1999), augment the labor factor according to its quality (understood as the average human capital) so that labor now enters as hL where $h = \exp(\phi(s))$, s is the average years of schooling, and $\phi(s)$ a piecewise linear function with varying slopes.¹³

We re-estimate equation 6 with the augmented labor variable. In the parametric results (not shown), for both gross and net R&D, labor growth is now significant in all specifications. Returns to physical investment remain broadly unchanged. R&D loses significance in several specifications, however, where significant, the magnitudes are very similar to the previous case. As documented earlier, however, parametric specifications hide important variance across level of development. Figures 8a and 8b are the corresponding analogues to Figures 6a and 6b respectively. We immediately note that the marked upward trend in the coefficient on labor growth among advanced countries has now been eliminated, and now there is no obvious trend across distance from the frontier. The upward trend in the coefficient is due to the higher quality of labor. The pattern of physical investment is similar to before. The coefficient on initial output changes little with, again, a discrete fall around -1.5.

¹³ $\phi(s) = 0.134s$ if $s \leq 4$, $\phi(s) = 0.134 \times 4 + 0.101(s - 4)$ if $4 < s < 8$, $\phi(s) = 0.134 \times 4 + 0.101 \times 4 + 0.068(s - 8)$ if $8 < s$.

The returns to R&D retain their inverted U shape both with and without instrumentation. The decline among poor countries appears as dramatic as before, particularly with the estimates using external instruments which appear precisely estimated and with the most contrast across the development trajectory. For poor countries, the rate of return to RD appears negative. The shape of the previous return to R&D curve does not appear to be driven by unmeasured human capital

4.5 TFP

The fact that the coefficients on the non R&D covariates now appear largely constant suggests constraining them to be so and working directly with TFP as done by Griffith et al. (2004) is arguably defensible. We generate TFP or Solow residual by compounding physical capital analogously to the above for R&D and imposing parameters $g = 0.5$ and $\delta = 0.08$. This, along the assumption that $\gamma_k = 1/3$ and $y_l = 2/3$, allow us to compute our own estimate of TFP as follows:

$$TFP = \frac{Y/L}{(K/L)^{\gamma_k} \times h^{y_l}}$$

Table 3 reports the parametric estimates of returns to R&D analogous to those previous, but using our estimate of TFP growth as the dependent variable. The estimates differ significantly in the pooled OLS, where R&D now enters significantly and of an order of magnitude similar to the fixed effect regressions. However, the base uninstrumented FE regressions are very close to those using GDP growth as the dependent variable, whether gross or net.

Figure 9 shows the evolution of the returns to R&D investments to TFP growth varying according to the distance to the technological frontier. This is now measured as the distance to the technological frontier, log of the ratio $TFP/TPF_{frontier}$. Although the estimated

standard errors are substantially larger, and the variance in the R&D parameter somewhat less, the inverted U pattern is still discernible, especially in the base and external instruments cases. Still, the less crisp results suggest that imposing the parameter constraints is costly and that the more flexible formulation is preferred.

5 Discussion

In sum, the inverted U pattern is broadly robust across specifications and choice of instruments. As discussed earlier, such a pattern can easily be generated theoretically by the interaction of the Schumpeterian gains from backwardness and the increasing scarcity of the necessary R&D complements with distance to the technological frontier. Two puzzles remain.

First, how do we account for the negative returns found among the very poorest countries in numerous of these specifications, and significantly so in the externally instrumented case? Arguably, this may arise from the increasing public sector component in total R&D with distance from the frontier that permits substantial positive spending on R&D even when not economically justified. In the advanced countries roughly 65% of R&D is undertaken by the productive sector while in poorer countries this share falls to 30%. With government undertaking or subsidizing a large share of R&D that is not economically justified, the country-wide return falls below that of private R&D alone. Young (1992), for instance, argues that that some large component of R&D investment in Singapore constituted high tech white elephants. In the limit, such investment is completely wasted and by drawing resources away from other competing demands or by raising taxes on the private sector, it may cause returns to become negative. This result has precedent in the literature on the level and composition of fiscal spending. Devarajan et al. (1996), for instance, find a negative impact with an increased share of government spending devoted to capital expenditures, arguing that when such spending becomes “excessive” the marginal return becomes negative. Alesina et al. (2002) more recently, find negative impacts of government

spending due to crowding out through higher wages, etc. These may be exacerbated in LDCs where the benefit of R&D spending to the private sector, as we document, is low, but the competition for very scarce resources may be more intense.

Second, do these findings imply that the massive increase in R&D spending in China and India is waste? Not necessarily. The answer to the China/India puzzle may lie in the fact that most this innovative effort may be done on imported innovation platforms that provide all the necessary complementary factors, within multinational corporations. As Branstetter et al. (2012) show in 2010 roughly 75% of patenting being done is done in or jointly with multinational corporations. This is very distinct from the pattern seen in Korea and Taiwan where the vast majority are, and have been since the 1970s, indigenous patents. To the degree that R&D maps to patents, then the puzzle is partly explained by the fact that China and India have imported the innovation infrastructure- management, networks, and corporate structure- thereby potentially offsetting the usual degradation that happens with distance from the frontier. But it also suggests that the innovation statistics may be vastly overstating the effort made by indigenous firms as well as the quality of the national innovation system. If the work is being done inside of Taiwanese or US firms, then knowledge, product and entrepreneurial spillovers may be very small. Further, this says nothing about the quality of the innovative effort going on in purely Chinese firms and whether it may be hampered by the absence of the usual complementary factors found in other emerging countries.

6 Conclusions

Using a panel of country level data on R&D this paper first confirms that despite presumed gains from Schumpeterian backwardness poor countries tend to do very little R&D. We document that global returns to R&D across the whole sample are consistent with those found earlier, although they do fall with the introduction of internal and external instruments.

We then employ recent advances in Instrumental Variable Varying Coefficient estimation techniques to map the returns to R&D across the development process. We confirm Griffith et al. (2004)'s finding of increasing returns with distance from the frontier up to about the level of modern day Mexico. However, we then document an inverted U pattern where returns fall with further distance from the frontier and even potentially can become negative. Again, these results are robust to instrumentation, controlling for human capital embodied in labor, and sample. The IVVC estimates also suggest that the convergence parameter also follows a broadly similar pattern suggesting that the gains from non-R&D catch up also vary and peak among the middle income countries.

Our findings are consistent with a countervailing effect of increasingly scarce complements to R&D spending with distance from the frontier that eventually offsets the gains from Schumpeterian backwardness. Poor countries lack the high level human capital, research infrastructure, and a sophisticated private sector that could both exploit knowledge transfer and provide feedback to the RD process, as well as generally weaker investment climates that depresses overall profitability. The results suggest that for middle income countries, a great window of opportunity exists, and a strong effort to lift the quality and magnitude of R&D spending is merited. However, with poorer countries, focus on R&D spending alone is likely to yield poor results. Though it is difficult to document empirically, the findings, along with a substantial literature, suggests that complementary efforts in improving the quality of human capital, strengthening research institutions, ordering the national innovation system, and raising the sophistication of the private sector are necessary complements to increased spending on R&D. China and India's spectacular growth in R&D may be justified by the fact that multinationals do most of the patentable R&D and hence provide the necessary complementary factors.

References

- Acemoglu, D., Aghion, P., and Zilibotti, F. (2006). Distance to Frontier, Selection, and Economic Growth. *Journal of the European Economic association*, 4(1):37–74.
- Acemoglu, D. and Zilibotti, F. (2001). Productivity Differences. *The Quarterly Journal of Economics*, 116(2):563–606.
- Aghion, P., Askenazy, P., Berman, N., Cetto, G., and Eymard, L. (2010). Credit Constraints and the Cyclicity of R&D Investment: Evidence from France. Technical report.
- Aghion, P. and Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica*, 60(2):323–351.
- Aghion, P., Mayer-Foulkes, D., and Howitt, P. (2005). The Effect of Financial Development on Convergence: Theory and Evidence. *Quarterly Journal of Economics*, 120:173–222.
- Aghion, P. A., Howitt, P. A., and Peñalosa, C. G. (1998). *Endogenous Growth Theory*. MIT Press.
- Alesina, A., Ardagna, S., Perotti, R., and Schiantarelli, F. (2002). Fiscal Policy, Profits, and Investment. *American Economic Review*, 92(3):571–589.
- Aw, B. Y., Roberts, M. J., and Xu, D. Y. (2008). R&D Investments, Exporting, and the Evolution of Firm Productivity. *The American Economic Review*, 98(2):451–456.
- Azariadis, C. and Drazen, A. (1990). Threshold Externalities in Economic Development. *The Quarterly Journal of Economics*, 105(2):501.
- Barro, R. and Lee, J. (2001). International Data on Educational Attainment: Updates and Implications. *Oxford Economic Papers*, 53(3):541.
- Barro, R. and Sala-i Martin, X. (2003). Economic Growth.
- Basu, S. and Weil, D. (1998). Appropriate Technology and Growth. *The Quarterly Journal of Economics*, 113(4):1025–1054.
- Baumol, W., Nelson, R., and Wolff, E. (1994). *Convergence of Productivity: Cross-national Studies and Historical Evidence*. Oxford University Press, USA.
- Baumol, W. J. (1990). Entrepreneurship: Productive, Unproductive, and Destructive. *Journal of Political Economy*, 98(5):893–921.
- Benhabib, J. and Spiegel, M. (1994). The Role of Human Capital in Economic Development Evidence from Aggregate Cross-country Data. *Journal of Monetary Economics*, 34(2):143–173.
- Benhabib, J. and Spiegel, M. (2005). Human Capital and Technology Diffusion. *Handbook of Economic Growth*, 1:935–966.
- Bloom, N. (2007). Uncertainty and the Dynamics of R&D. *American Economic Review*, 97(2):250–255.

- Bloom, N. and Van Reenen, J. (2007). Measuring and Explaining Management Practices Across Firms and Countries. *The Quarterly Journal of Economics*, 122(4):pp. 1351–1408.
- Bond, S., Harhoff, D., and Reenen, J. V. (2010). Investment, R&D and Financial Constraints in Britain and Germany. In *Contributions in Memory of Zvi Griliches*, NBER Chapters, pages 433–460. National Bureau of Economic Research, Inc.
- Branstetter, L., Li, G., and Veloso, F. (2012). The Globalization of R&D: China, India and the Rise of International Co-invention. Technical report.
- Brock, W. and Durlauf, N. (2000). Growth Economics and Reality. Technical report, National Bureau of Economic Research.
- Cai, Z., Das, M., Xiong, H., and Wu, X. (2006). Functional Coefficient Instrumental Variables Models. *Journal of Econometrics*, 133(1):207–241.
- Caselli, F. (2001). Cross-Country Technology Diffusion: The Case of Computers. *The American Economic Review*.
- Caselli, F. (2005). Accounting for Cross-Country Income Differences. *Handbook of Economic Growth*, 1:679–741.
- Cleveland, W. S. and Devlin, S. J. (1988). Locally weighted regression: an approach to regression analysis by local fitting. *Journal of the American Statistical Association*, 83(403):596–610.
- Coe, D. and Helpman, E. (1995). International R&D Spillovers. *European Economic Review*, 39(5):859–887.
- Coe, D., Helpman, E., and Hoffmaister, A. (1997). North-South R & D Spillovers. *The Economic Journal*, pages 134–149.
- Cohen, W. and Levinthal, D. (1989). Innovation and Learning: the Two Faces of R & D. *The Economic Journal*, 99(397):569–596.
- Comin, D., Easterly, W., and Gong, E. (2010). Was the Wealth of Nations Determined in 1000 BC? *American Economic Journal. Macroeconomics*, 2(3):65–97.
- Comin, D. and Hobijn, B. (2004). Cross-country Technology Adoption: Making the Theories Face the Facts. *Journal of Monetary Economics*, 51(1):39–83.
- Comin, D. and Hobijn, B. (2009). Lobbies and Technology Diffusion. *The Review of Economics and Statistics*, 91(2):229–244.
- Comin, D. A., Dmitriev, M., and Rossi-Hansberg, E. (2012). The Spatial Diffusion of Technology. Technical report, National Bureau of Economic Research.
- Crosby, M. (2000). Patents, Innovation and Growth. *Economic Record*, 76(234):255–262.
- Deolalikar, A. and Röller, L. (1989). Patenting by Manufacturing Firms in India: Its Production and Impact. *The Journal of Industrial Economics*, pages 303–314.

- Desdoigts, A. (1999). Patterns of Economic Development and The Formation of Clubs. *Journal of Economic Growth*, 4(3):305–330.
- Devarajan, S., Swaroop, V., and Heng-fu, Z. (1996). The Composition of Public Expenditure and Economic Growth. *Journal of Monetary Economics*, 37(2-3):313–344.
- Doraszelski, U. and Jaumandreu, J. (2013). R&D and Productivity: Estimating Endogenous Productivity. *The Review of Economic Studies*.
- Durlauf, S. and Johnson, P. (1995). Multiple Regimes and Cross-Country Growth Behaviour. *Journal of Applied Econometrics*, 10(4):365–384.
- Durlauf, S. N., Kourtellos, A., and Minkin, A. (2001). The local solow growth model. *European Economic Review*, 45(4):928–940.
- Eaton, J. and Kortum, S. (1999). International Technology Diffusion: Theory and Measurement. *International Economic Review*, 40(3):537–570.
- Eaton, J. and Kortum, S. (2001). Technology, Trade, and Growth: A Unified Framework. *European Economic Review*, 45(4):742–755.
- Fan, J. and Zhang, W. (1999). Statistical Estimation in Varying Coefficient Models. *The Annals of Statistics*, 27(5):1491–1518.
- Fan, J. and Zhang, W. (2000). Simultaneous Confidence Bands and Hypothesis Testing in Varying-coefficient Models. *Scandinavian Journal of Statistics*, 27(4):715–731.
- Forbes, N. and Wield, D. (2000). Managing R&D in Technology-Followers. *Research Policy*, 29(9):1095–1109.
- Foster, A. D. and Rosenzweig, M. R. (1996). Technical Change and Human-Capital Returns and Investments: Evidence from the Green Revolution. *The American Economic Review*, 86(4):pp. 931–953.
- Galor, O. (1996). Convergence? Inferences from Theoretical Models. *The Economic Journal*, pages 1056–1069.
- Ginarte, J. and Park, W. (1997). Determinants of Patent Rights: A Cross-National Study. *Research Policy*, 26(3):283–301.
- Griffith, R., Harrison, R., and Van Reenen, J. (2006). How Special is the Special Relationship? Using the Impact of US R&D Spillovers on UK Firms as a Test of Technology Sourcing. *The American Economic Review*, 96(5):1859–1875.
- Griffith, R., Redding, S., and Reenen, J. (2004). Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. *Review of Economics and Statistics*, 86(4):883–895.
- Griliches, Z. (1986). Productivity, R&D, and the Basic Research at the Firm Level in the 1970’s. *The American Economic Review*.

- Griliches, Z. (1987). R&D and Productivity: Measurement Issues and Econometric Results. *Science*, 237(4810):31.
- Griliches, Z. and Lichtenberg, F. (1984). R&D and Productivity Growth at the Industry Level: is There Still a Relationship?
- Hall, B. and Mairesse, J. (1995). Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms. *Journal of Econometrics*, 65(1):263–293.
- Hall, B. H. (2010). Measuring the Returns to R&D: The Depreciation Problem. In *Contributions in Memory of Zvi Griliches*, pages 341–381. Annales D’Économie et de Statistique, 79-80, July-December 2005.
- Hall, B. H. and Lerner, J. (2009). The Financing of R&D and Innovation. NBER Working Papers 15325, National Bureau of Economic Research, Inc.
- Hall, B. H., Mairesse, J., and Mohnen, P. (2010). Measuring the Returns to R&D. *Handbook of the Economics of Innovation*, 2:1033–1082.
- Hall, R. and Jones, C. (1999). Why Do Some Countries Produce So Much More Output Per Worker Than Others? *The Quarterly Journal of Economics*, 114(1):83–116.
- Hansen, B. (2000). Sample Splitting and Threshold Estimation. *Econometrica*, 68(3):575–603.
- Hastie, T. and Tibshirani, R. (1993). Varying-Coefficient Models. *Journal of the Royal Statistical Society. Series B (Methodological)*, pages 757–796.
- Howitt, P. (2000). Endogenous Growth and Cross-country Income Differences. *American Economic Review*, pages 829–846.
- Howitt, P. and Mayer-Foulkes, D. (2002). R&D, Implementation and Stagnation: A Schumpeterian Theory of Convergence Clubs. Technical report, National Bureau of Economic Research.
- Howitt, P. and Mayer-Foulkes, D. (2005). R&D, Implementation, and Stagnation: A Schumpeterian Theory of Convergence Clubs. *Journal of Money, Credit and Banking*, 37(1):147–77.
- Jones, C. and Williams, J. (1998). Measuring the Social Return to R&D. *The Quarterly Journal of Economics*, 113(4):1119.
- Jones, C. I. (2011). Intermediate Goods and Weak Links in the Theory of Economic Development. *American Economic Journal: Macroeconomics*, 3(2):1–28.
- Kao, C., Chiang, M.-H., and Chen, B. (1999). International R&D Spillovers: An Application of Estimation and Inference in Panel Cointegration. *Oxford Bulletin of Economics and Statistics*, 61(S1):691–709.
- Keller, W. (2002). Geographic Localization of International Technology Diffusion. *The American Economic Review*, 92(1):120–142.

- Keller, W. (2004). International Technology Diffusion. *Journal of Economic Literature*, 42(3):752–782.
- Klenow, P. J. and Rodriguez-Clare, A. (2005). Externalities and Growth. *Handbook of Economic Growth*, 1:817–861.
- Kourtellos, A. (2001). Modelling Coefficient Heterogeneity in Cross-Country Growth Regression Models. *University of Wisconsin-Madison, PhD Thesis*.
- Kourtellos, A. (2002). Modeling Parameter Heterogeneity in Cross Country Growth Regression Models. *University of Cyprus Working Papers in Economics*.
- Kremer, M. (1993). The O-ring Theory of Economic Development. *The Quarterly Journal of Economics*, 108(3):551–575.
- Lach, S. (1995). Patents and Productivity Growth at The Industry Level: A First Look. *Economics Letters*, 49(1):101–108.
- Lederman, D., Maloney, W., America, W. B. L., and the Caribbean Regional Office. Office of the Chief Economist. Regional Studies Program (2003). *R&D and Development*, volume 3024. World Bank, Latin America and the Caribbean Region, Office of the Chief Economist, Regional Studies Program.
- Lederman, D. and Saenz, L. (2005). Innovation and Development Around the World, 1960–2000. *Policy Research Working Paper Series*.
- Lichtenberg, F. (1993). R&D Investment and International Productivity Differences. Technical report, National Bureau of Economic Research.
- Liu, Z. and Stengos, T. (1999). Non-linearities in Cross-Country Growth Regressions: A Semiparametric Approach. *Journal of Applied Econometrics*, 14(5):527–538.
- Lucas, R. (1988). On the Mechanics of Economic Development. *Journal of Monetary Economics*, 22(1):3–42.
- Mansfield, E. (1965). Rates of Return From Industrial Research and Development. *The American Economic Review*, 55(1/2):310–322.
- Maskus, K. and McDaniel, C. (1999). Impacts of the Japanese Patent System on Productivity growth. *Japan and the World Economy*, 11(4):557–574.
- Mohnen, P. and Roller, L.-H. (2005). Complementarities in Innovation Policy. *European Economic Review*, 49(6):1431–1450.
- Mulkay, B., Hall, B. H., and Mairesse, J. (2000). Firm Level Investment and R&D in France and the United States: A Comparison. NBER Working Papers 8038, National Bureau of Economic Research, Inc.
- Murphy, K. M., Shleifer, A., and Vishny, R. W. (1991). The Allocation of Talent: Implications for Growth. *The Quarterly Journal of Economics*, 106(2).

- Nelson, R. and Phelps, E. (1966). Investment in Humans, Technological Diffusion, and Economic Growth. *The American Economic Review*, 56(1/2):69–75.
- Nelson, R. R. (2005). *Technology, Institutions, and Economic Growth*. Harvard University Press, Cambridge, Mass.
- Oulton, N. and Young, G. (1996). How High Is the Social Rate of Return to Investment. *Oxford Review of Economic Policy*, 12(2):48–69.
- Pack, H. (1994). Endogenous Growth Theory: Intellectual Appeal and Empirical Shortcomings. *The Journal of Economic Perspectives*, 8(1):55–72.
- Parente, S. L. and Prescott, E. C. (1994). Barriers to Technology Adoption and Development. *Journal of political Economy*, pages 298–321.
- Park, W. (2001). Intellectual Property and Patent Regimes. *Economic Freedom of the World: 2001 Annual Report*, pages 101–118.
- Park, W. (2008). International Patent Protection: 1960–2005. *Research Policy*, 37(4):761–766.
- Pavitt, K. (2001). Public Policies to Support Basic Research: What Can The Rest of The World Learn From US Theory and Practice?(And What They Should Not Learn). *Industrial and Corporate Change*, 10(3):761–779.
- Potterie, B. and Lichtenberg, F. (2001). Does Foreign Direct Investment Transfer Technology Across Borders? *Review of Economics and Statistics*, 83(3):490–497.
- Rodrik, D. (2001). The Global Governance of Trade: As if Development Really Mattered.
- Rosenberg, N. (2000). *Schumpeter and the Endogeneity of Technology : Some American Perspectives*. Routledge, London.
- Sveikauskas, L. (2007). R&D and Productivity Growth: A Review of the Literature. *Bureau of Labor Statistics Working Paper*, 408.
- Thompson, M. and Rushing, F. (1996). An Empirical Analysis of the Impact of Patent Protection on Economic Growth. *Journal of Economic Development*, 21(2):61–79.
- Thompson, M. and Rushing, F. (1999). An Empirical Analysis of the Impact of Patent Protection on Economic Growth: an Extension. *Journal of Economic Development*, 24(1):67–76.
- World Economic Forum, Schwab, K. et al. (2012). The Global Competitiveness Report 2010–2011. *Geneva, Switzerland*.
- Young, A. (1992). A Tale of Two Cities: Factor Accumulation and Technical Change in Hong Kong and Singapore. In *NBER Macroeconomics Annual 1992*. MIT Press.
- Young, A. (1993). Invention and Bounded Learning by Doing. *Journal of Political Economy*, pages 443–472.

Annex I Instruments Diagnostics

For the internal instrument, as expected the correlation with contemporaneous RD is high and the Cragg Donald Wald F test for the first stage is 179.63, above any reasonable critical value.

For IPRs, the correlation between the instrument and R&D is .66 and the first stage regression yields a Cragg Donald F test of 13.6, again, above the Stock and Yogo rule of thumb of 10. The origin of innovations in IPRs in trade agreements does not seem to be opening an alternate channel to growth through expanding trade. First, to establish that there is no independent effect of IPRs outside of the innovation channel, the IP index was introduced as a free standing term in the growth regressions with just R&D and found not to have an independent effect. The specifications also include a complete set of time dummies to account for disembodied technical change and general macroeconomic evolution. Robust regression under some parameter values can yield significance, however, this is not generally the case and never in the case of poor countries. Second, we include an explicit measure of trade openness, $(X+M)/GDP$, in the core parametric specifications and the RD results are left largely unaffected.¹⁴

We show that the IPR proxy is, in fact, weakly exogenous by running IP regime on its lagged value, lagged R&D and lagged growth plus time dummies. Neither lagged growth nor R&D are significant. The concern that lagged R&D or growth would lead to expectations of higher innovative effort in the future, and hence a need to establish intellectual property rights, seems ill founded. Only lagged IP and two time dummies have explanatory power suggesting exogenous time specific pressures. Growth enters negatively but is not significant (-1.14).

The Sargan test for overidentification also suggests the appropriateness of the instrument. The varying parameter technique can only manage one instrument. However, as a test for exogeneity, we run a Sargan test on the sub components of the index and also serially run the aggregate IP index and each one of the sub-components individually. The Sargan test for overidentification accepts the null of exogenous- that they are uncorrelated with the error and correctly excluded from the second stage.

Together, along with the findings below that the returns to RD indeed fall substantially when instrumented, these tests suggest that this is a useful complement to the internal instruments traditionally used in the literature.

¹⁴In fact, the openness measure enters only at the 18% level in the fixed effects specifications

Figures and Tables

Figure 1: R&D vs. Level of Development

Source: R&D series from UNESCO, OECD, Taiwan Statistical Yearbook and Lederman and Saenz (2005). GDP/Capita from Penn World Tables.

Figure 2: R&D vs. Level of Development (Selected Countries)

Source: R&D series from UNESCO, OECD, Taiwan Statistical Yearbook, and Lederman and Saenz (2005). GDP/Capita from Penn World Tables.

Figure 3: Perceived Quality of Scientific Research Institutions vs. Distance to the Technological Frontier

Figure 4: University-Industry Collaboration in R&D vs. Distance to the Technological Frontier

Source: Global Competitiveness Report (2012). Response of private sector on a scale of 1-7 to “How would you assess the quality of scientific research institutions in your country? [1=very poor; 7=the best their field internationally].” Response of private sector on a scale of 1-7 to “What extent do business and universities collaborate on research and development (R&D) in your country? [1=very poor; 7=the best their field internationally].” 2011-2012 weighted average. Distance to the frontier is GDP per capita relative to highest country value.

Figure 5: Distribution of R&D, Educational Attainment, and IPR Regime vs. Distance to Technological Frontier

Source: R&D series from UNESCO, OECD, Taiwan Statistical Yearbook and Lederman and Saenz (2005). Data for education attainment comes from Barro and Lee (2001). Data for IPRs from Ginarte and Park (1997). The components are the coverage of patent laws across seven industries, membership in three key international patent agreements, provisions for loss of rights for loss of protection, three types of enforcement mechanisms, and the duration of patents relative to international standards. Distance to the frontier is GDP per capita relative to highest country value.

Figure 6a: Coefficients on Physical Investment, Labor Growth and Initial Output vs. Distance to Technological Frontier (Varying coefficients)

Note: Using Fan and Shang (1999,2000) and Cai et al.(2006), we estimate $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real GDP, α is a sample-wide fixed time effect, Y_{-1} lagged income, F the matrix of productive factors including the growth of labor, and the investment in both physical and innovative capital expressed as a share of income. All series demeaned to account for country fixed effects. All parameters are allowed to vary with distance to the technological frontier. Internal instrument is a 10 year lag of R&D. External instrument is IPR regime as generated by Ginarte and Park (1997). Horizontal lines are parametric FE estimates with 5% confidence interval.

Figure 6b: Rate of Return to RD (Varying coefficients, Instruments)

Note: Using Fan and Shang (1999,2000) and Cai et al.(2006), we estimate $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real GDP, α is a sample-wide fixed time effect, Y_{-1} lagged income, F the matrix of productive factors including the growth of labor, and the investment in both physical and innovative capital expressed as a share of income. All series demeaned to account for country fixed effects. All parameters are allowed to vary with distance to the technological frontier. Internal instrument is a 10 year lag of R&D. External instrument is IPR regime as generated by Ginarte and Park (1997). Horizontal lines are parametric FE estimates with 5% confidence interval.

Figure 7: Rate of Return to RD Relative to Technological Frontier (Representative Countries)

Note: Using Fan and Shang (1999,2000) and Cai et al.(2006), we estimate $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real GDP, α is a sample-wide fixed time effect, Y_{-1} lagged income, F the matrix of productive factors including the growth of labor, and the investment in both physical and innovative capital expressed as a share of income. All series demeaned to account for country fixed effects. All parameters are allowed to vary with distance to the technological frontier. Country labels refer to the returns at a country of that distance from the frontier and do not correspond to a particular country.

Figure 8a: Coefficients on Physical Investment, Labor Growth and Initial Output vs. Distance to Technological Frontier (Varying Coefficients, adjustment for Labor Quality)

Note: Using Fan and Shang (1999,2000) and Cai et al.(2006), we estimate $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real GDP, α is a sample-wide fixed time effect, Y_{-1} lagged income, F the matrix of productive factors including the growth of labor, and the investment in both physical and innovative capital expressed as a share of income. All series demeaned to account for country fixed effects. All parameters are allowed to vary with distance to the technological frontier. Internal instrument is a 10 year lag of RD. External instrument is IPR regime as generated by Ginarte and Park (1997). Labor adjusted for quality (understood as the average human capital) using Caselli (1005). Labor now enters as hL , where $h = \exp(\phi(s))$, s is the average years of schooling, and $\phi(s)$ a piecewise linear function with varying slopes. Horizontal lines are parametric FE estimates with 5% confidence interval.

Figure 8b: Rate of Return to RD (Varying Coefficients, Adjusted for Labor Quality, Instruments)

Note: Using Fan and Shang (1999,2000) and Cai et al.(2006), we estimate $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real GDP, α is a sample-wide fixed time effect, Y_{-1} lagged income, F the matrix of productive factors including the growth of labor, and the investment in both physical and innovative capital expressed as a share of income. All series demeaned to account for country fixed effects. All parameters are allowed to vary with distance to the technological frontier. Internal instrument is a 10 year lag of RD. External instrument is IPR regime as generated by Ginarte and Park (1997). Labor adjusted for quality (understood as the average human capital) using Caselli (1005). Labor now enters as hL , where $h = \exp(\phi(s))$, s is the average years of schooling, and $\phi(s)$ a piecewise linear function with varying slopes. Horizontal lines are parametric FE estimates with 5% confidence interval.

Figure 9: Rate of Return to RD (TFP) vs. Distance to Technological Frontier (Varying Parameters)

Notes: Estimated as $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real TFP, α is a sample-wide fixed time effect, Y_{-1} lagged TFP, F investment in R&D expressed as a share of income. All series demeaned to account for country fixed effects. Internal instrument is a 10 year lag of TFP. External instrument is IPR regime as generated by Ginarte and Park (1997).

Table 1: Summary Statistics

	Growth	Investment	Labor growth	Attainment	R&D	IPR
<i>OECD countries</i>						
1961 - 1965	0.061	0.275	0.014	7.144	0.013	2.603
1966 - 1970	0.054	0.272	0.011	7.223	0.012	2.719
1971 - 1975	0.039	0.278	0.012	8.020	0.012	2.703
1976 - 1980	0.032	0.255	0.010	8.466	0.013	3.069
1981 - 1985	0.021	0.228	0.010	8.739	0.016	3.278
1986 - 1990	0.030	0.228	0.008	9.197	0.017	3.523
1991 - 1995	0.020	0.206	0.008	9.670	0.018	4.173
1996 - 2000	0.035	0.213	0.007	10.090	0.020	4.410
<i>Non OECD countries</i>						
1961 - 1965	0.059	0.200	0.025	2.873	0.003	1.505
1966 - 1970	0.051	0.198	0.024	3.011	0.002	1.446
1971 - 1975	0.047	0.219	0.026	3.809	0.004	1.371
1976 - 1980	0.058	0.261	0.027	4.269	0.006	1.357
1981 - 1985	0.024	0.235	0.025	4.968	0.005	1.622
1986 - 1990	0.038	0.229	0.023	5.477	0.006	1.643
1991 - 1995	0.044	0.231	0.022	5.926	0.005	2.520
1996 - 2000	0.037	0.229	0.020	6.689	0.004	3.179

Note: GDP/capita, Investment, Labor from Penn World Tables. Educational Attainment from Barro and Lee. R&D series from UNESCO, OECD, Taiwan Statistical Yearbook and Lederman and Saenz (2005). IPR regime index from Ginarte and Park (1997). The components are the coverage of patent laws across seven industries, membership in three key international patent agreements, provisions for loss of rights for loss of protection, three types of enforcement mechanisms, and the duration of patents relative to international standards. Advanced countries include: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israël, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

Table 2: Returns to R&D (Parametric)

	POOLED			POOLED WITH FE		
	No IV	Internal	External	No IV	Internal	External
R&D ("Gross")	0.262 [0.180]	0.176 [0.202]	1.074** [0.492]	0.743*** [0.220]	0.503* [0.302]	-0.103 [0.805]
Investment	0.208*** [0.023]	0.208*** [0.023]	0.208*** [0.024]	0.268*** [0.025]	0.269*** [0.025]	0.272*** [0.026]
Labor Growth	0.840*** [0.131]	0.812*** [0.134]	1.095*** [0.198]	0.239 [0.226]	0.223 [0.227]	0.185 [0.238]
Initial GDP	0 [0.001]	0 [0.001]	-0.002 [0.001]	-0.050*** [0.006]	-0.049*** [0.006]	-0.045*** [0.008]
Observations	227	227	227	227	227	227
F(Cragg-Donald)			37.72			13.6

	POOLED			POOLED WITH FE		
	No IV	Internal	External	No IV	Internal	External
R&D ("Net")	0.757** [0.313]	0.619* [0.371]	2.109** [0.955]	1.309*** [0.339]	1.679*** [0.543]	-0.182 [1.426]
Investment	0.204*** [0.023]	0.205*** [0.023]	0.197*** [0.024]	0.262*** [0.025]	0.259*** [0.025]	0.273*** [0.028]
Labor Growth	0.858*** [0.124]	0.840*** [0.127]	1.038*** [0.176]	0.218 [0.224]	0.226 [0.225]	0.188 [0.235]
Initial GDP	-0.001 [0.001]	0 [0.001]	-0.002 [0.001]	-0.050*** [0.006]	-0.052*** [0.006]	-0.045*** [0.008]
Observations	227	227	227	227	227	227
F(Cragg-Donald)			29.16			10.28

Notes: Estimated as $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real GDP, α is a sample-wide fixed time effect, Y_{-1} lagged income, F the matrix of productive factors including the growth of labor, and the investment in both physical and innovative capital expressed as a share of income. Internal instrument is a 10 year lag of TFP. External instrument is IPR regime as generated by Ginarte and Park (1997) Net results use a rate of depreciation of R&D of .05 following Hall and Mairesse (1995).

Table 3: Returns to R&D (TFP, Parametric)

	POOL			POOL WITH FE		
	No IV	Internal	External	No IV	Internal	External
R&D (Gross)	0.615*** [0.154]	0.561*** [0.170]	1.271*** [0.331]	0.893*** [0.242]	0.714** [0.349]	2.985* [1.692]
Initial TFP	-0.002 [0.002]	-0.002 [0.002]	-0.007** [0.003]	-0.065*** [0.010]	-0.062*** [0.010]	-0.096*** [0.027]
Observations	226	226	226	226	226	226
F(Cragg-Donald)			67.89			4.45

	POOL			POOL WITH FE		
	No IV	Internal	External	No IV	Internal	External
R&D (Net)	1.290*** [0.281]	1.281*** [0.331]	3.001*** [0.802]	1.310*** [0.363]	1.557*** [0.593]	4.806* [2.808]
Initial TFP	-0.002 [0.002]	-0.002 [0.002]	-0.009** [0.003]	-0.061*** [0.009]	-0.063*** [0.010]	-0.086*** [0.022]
Observations	226	226	226	226	226	226
F(Cragg-Donald)			37.12			3.83

Notes: Estimated as $\dot{y} = \alpha + \delta Y_{-1} + \beta F + \epsilon$ where $\dot{y}$ is real growth rate of real TFP, α is a sample-wide fixed time effect, Y_{-1} lagged TFP, F investment in R&D expressed as a share of income. Internal instrument is a 10 year lag of TFP. External instrument is IPR regime as generated by Ginarte and Park (1997) All series demeaned to account for country fixed effects. Net results use a rate of depreciation of R&D of .05 following Hall and Mairesse (1995).