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# “ The "farthest" need the best. Human capital composition and development-specific economic growth”

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### *Abstract*

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We provide robust and compelling evidence of the marked impact of tertiary education on the economic growth of less developed countries and of its the relatively smaller impact on the growth of developed ones. Our results argue in favor of the accumulation of high skill levels especially in technologically underdeveloped countries and, contrary to common wisdom, independently of the fact that these economies might initially produce low(er)-technology goods or perform technology imitation. Our results are robust to the different measures used in proxying human capital and to the adjustments made for cross-country differences in the quality of education. Country-specific institutional quality, as well as other indicators including legal origin, religious fractionalization and openness to trade have been used to control for the robustness of the results. These factors are also shown to speed up technology convergence thereby confirming previous empirical studies. Our estimates tackle problems of endogeneity by adopting a variety of techniques, including instrumental variables (for both panel and cross-section analyses) and the two-step efficient dynamics system GMM.

***JEL classification:*** I20, O30, O40

***Keywords:*** Economic growth, human capital, imitation, innovation, convergence.

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## 1. Introduction

Where has all the education gone? With this question Lant Pritchett (2001) started to raise questions about the puzzlingly weak macroeconomic empirical evidence for the impact of human capital on economic growth. In fact, even though the predictions of endogenous growth theory had been consistently pointing to human capital as the engine of growth (Aghion and Howitt, 1992; Romer, 1990), the estimated impact of education proxies on economic growth has been shown to be negative or, at best, null in a wide collection of influential empirical studies. Studies by Krueger and Lindahl (2001), Benhabib and Spiegel (1994) and Temple (2001) are among those that lend support to this puzzling evidence, concluding that the impact of human capital on economic growth might have been somewhat overstated.

Among panel data studies, Caselli, Esquivel and Lefort (1996) and Bond, Heffer and Temple (2001) also failed to find the expected positive coefficient for the impact of human capital on economic growth<sup>1</sup>.

More recently, and as a response to these empirical results, a new strand of literature has sought to redeem the role of education and human capital by identifying various potential causes of this puzzling outcome. In two influential studies, de la Fuente and Domenech (2001) and Cohen and Soto (2006) argue that the human capital datasets used in previous growth regressions (and especially in the panel data studies) were largely unreliable and of poor quality. After detecting the presence of substantial measurement errors in earlier international estimates of the average number of years of schooling, these authors have been able to produce more robust human capital proxies that consistently outperform previous sources.

In this debate centered on the quality of human capital proxies, an equally interesting and influential hypothesis has been proposed in the literature to explain the (lack of) empirical evidence of the impact of average measures of human capital on economic growth. In a recent paper, Vandenbussche, Aghion and Meghir (2006) (henceforth VAM) propose an original theoretical model in which different types of human capital (i.e., skilled vs. unskilled workers) perform different tasks (i.e., innovation vs. imitation) depending on the relative distance of the economy from the technology frontier (i.e., when close or far away from the technological leader).

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<sup>1</sup> The aforementioned studies are just a few of many influential examples of a broader empirical literature that has struggled to find the expected positive effect of human capital on growth.

Hence, the crucial dimension under analysis becomes the relative "composition" (rather than the average level) of human capital in each country<sup>2</sup>.

VAM's theoretical result is based crucially on a dual hypothesis. On the one hand, the elasticity of skilled labor is assumed to be higher the closer the economy is to the technology frontier (and hence, when innovation is performed). In keeping with this assumption, it is argued that "a marginal increase in the fraction of skilled workers will enhance productivity growth all the more the economy is closer to the world technological frontier". However, as a consequence of this assumption, for those countries which lie far from the frontier, it is argued that "a marginal increase in the stock of unskilled human capital enhances productivity growth all the more the economy is further away from the technological frontier"<sup>3</sup>.

The second part of this theoretical result (which is concerned with the impact of unskilled labor on the growth of lagging economies) is somewhat troubling, since it would suggest that, in order to catch up with the world technological frontier, developing countries need to reduce, rather than increase, their skill endowment and that the beneficial effects of this reduction in skills would be greater the more under-developed these countries are<sup>4</sup>. In other words, VAM's theoretical results are based on the belief that imitation, being relatively easier to undertake than innovation, will be better performed by unskilled workers. Crucially, however, even if we agree that innovation is a more complex activity than imitation, there is no reason a priori to believe that skilled workers will be outperformed by unskilled workers in either of these activities, in particular that of imitation or technology adoption.

From an empirical point of view, VAM provide econometric evidence in support of their hypothesis. However, they do so for a small sample of 19 developed OECD countries (which, in practice, include only developed countries that already lie close to the world technology frontier) and neglect the analysis of human capital composition in an equally (or more) important part of

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<sup>2</sup> This assumption is not entirely new. Grossman and Helpman (1991) previously pointed out how the skill composition of the workforce (rather than the average level) could account for differences in economic performance. Specifically, they find that highly skilled labor is growth enhancing and vice versa.

<sup>3</sup> See Vandebussche, Aghion and Meghir (2006) - Proposition 1: "Under assumption (A1), a marginal increase in the stock of skilled human capital enhances productivity growth all the more the economy is closer to the world technological frontier. Correspondingly, a marginal increase in the stock of unskilled human capital enhances productivity growth all the more the economy is further away from the technological frontier".

<sup>4</sup> Despite the puzzling implications of VAM's theoretical hypothesis for developing countries, recent empirical studies such as Acemoglu, Aghion and Zilibotti (2006), Aghion, Boustan, Hoxby and Vandebussche (2009) and Acemoglu and Zilibotti (2001) have embraced similar assumptions regarding the elasticities of different types of human capital on economic growth.

the available sample of countries: developing countries and LDCs which lie considerably farther from the technology frontier.

With this study we aim to challenge VAM's empirical and theoretical results by providing new robust macroeconomic empirical evidence for an alternative hypothesis, according to which skilled (rather than unskilled) labor contributes to growth and especially to the growth of those countries lagging far behind the technological frontier.

There are various reasons to argue that skilled workers may be fundamental to the growth of countries and that perform technology adoption. A large body of robust microeconomic empirical evidence, (see Psacharopoulos, 1994; Psacharopoulos and Patrinos, 2002; Ichino and Winter-Ebmer, 1999 and Cohn and Addison, 1999), in fact, points to the much larger returns to investment in education (and especially of investment in tertiary education) at lower stages of development. The returns to tertiary education in LDCs are estimated to be almost twice as big as those in OECD countries. These results clash somewhat with the assumption made by VAM that the elasticity of skilled labor is should be any higher the closer an economy is to the world technology frontier (i.e. more developed).

The main argument underpinning our hypothesis is that technology imitation is not a "free lunch". On the contrary, technology imitation and adoption<sup>5</sup> are intrinsically skill-demanding activities that are better performed by educated than uneducated workers, as has been stressed elsewhere in the empirical literature. Maskus, Saggi and Puttitanun (2004), Mansfield, Schwartz and Wagner (1981), Coe and Helpman (1995) and Behnabib and Spiegel (2005) argue, for example, that the cost of the adaptation and imitation of technologies discovered at the frontier (or in other technological sectors) is positive<sup>6</sup> and that investment in human capital is thus needed in order to absorb this foreign leading technology.

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<sup>5</sup> Here, we draw a slight distinction between the terms "imitation" and "adoption". By imitation we refer to the process of discovering a product's (or technology's) characteristics, of unpacking it and of physically reproducing it with the aim of reselling this technology at a cheaper price (and lower quality) on international and domestic markets. By technology adoption, we refer to the process of discovering and unpacking a foreign technology with the aim of using it in the domestic economy for production. Consider, for example, the adoption of a process technology (i.e., the way in which a certain process is optimized) when this innovation can be adopted without having to pay the inventors for the organizational change.

<sup>6</sup> In particular, Mansfield, Schwartz and Wagner (1981) point out how, for 48 different products in the US chemical, drug, electronics and machinery industries, the costs of imitation were between 40 and 90% of the costs of innovation.

It might, in fact, be argued that the growth challenge faced by developing countries is not so much one of producing large "quantities" of imitated technological goods (a task that could indeed be accomplished by many developing countries endowed with large proportions of unskilled workers), but rather one of discovering the best ways to do so while minimizing the process-imitation costs involved in the adoption and imitation of these foreign technologies. In this way, they can compete on international markets with other imitators for whom this frontier technology is also potentially available.

In other words, some technologies are indeed more difficult to imitate than others<sup>7</sup> but, at the same time, they are also usually the most profitable ones. Such technologies are not immediately available to everyone regardless of their skills. On the contrary, the imitation or adoption of profitable, leading edge technologies requires specialized labor that has to be capable of performing technical reverse engineering (during the imitation process), of finding the right product to imitate and of locating its market niche, of understanding market trends and, at later stages of the imitation process, of being able to trade the imitated good on international markets. Indeed, the lack of trained workforce will simply impede the initiation and optimal development of the imitation process.

Ceteris paribus, those countries with better human capital will perform imitation activities better than those with relatively less skilled labor. What is more, an argument can be made for the fact that an increase in the share (or the quality) of the workforce will lead to better and more varieties of imitations being undertaken so that the imitated products sold on the international markets (or used in the domestic one) will be greater in their quantity/variety as well as of greater economic value.

To quote Calmfors, Corsetti, Flemming et al. (2003): "[skilled] people may represent small numbers but have a critical economic significance". This consideration also applies to developing countries, and especially to those countries where skilled and trained workers are indeed very scarce.

In the present contribution we from previous analyses in many respects by tackling, altogether, the different issues which we described above and that may affect the estimation of the causal relation between human capital and economic growth.

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<sup>7</sup> See for instance, Basu and Weil (1998) and Barro and Sala-i-Martin (1997)

As regards the quality of the human capital data, we draw on Cohen and Soto's (2006) international panel database for 88 countries for the period 1960-2000. This large dataset allows us to test the effect of different types of human capital on growth by differentiating between developed and developing countries.

Thus, thanks to the rich disaggregation of these human capital data we are able to test not only for the (likely) different impact that tertiary education may have on countries at different stages of development (developed vs. developing) but also to conduct this same analysis for secondary and primary education so that we might rank the magnitude of their effects on growth.

We run our empirical model using, as human capital composition proxies, (i) the average number of years of schooling in each education attainment level and (ii) the fraction of the workforce with primary, secondary and tertiary education in each year. We test our hypothesis on both the TFP "catch-up" empirical specification used by VAM and on the logistic technology diffusion function proposed by Behnabib and Spiegel (2005).

From the econometric point of view, in addition to the data quality problems, a further compelling issue has long affected the correct estimation of the impact that human capital may have on economic growth. Bils and Klenow (2000) provide convincing evidence that part of the positive effect of initial schooling levels on economic growth might be attributed to reverse causality. We carefully tackle endogeneity by applying a variety of suitable econometric techniques. Thus, we initially run our estimation by using fixed- and random-effect instrumental variable estimators in line with VAM. However, as pointed out by Aghion et al. (2009), the ability to correctly identify the causal relationship between human capital and economic growth is undermined by the use of lagged education spending as instruments, as they may be highly correlated over time within a country as well as being correlated to other variables, such as institutions.

We overcome this in two ways. On the one hand, we control (in all specifications) for institutional quality, adding this variable as an explanatory control to our "catch-up" specifications. We proxy for institutional quality by using the panel data provided in the Economic Freedom of the World Index (EFW). However, since institutional quality may itself be endogenous with respect to growth, we also instrument for it by using exogenous characteristics of the countries that have been shown to be highly correlated with institutions, such as their geographical location (Hall and Jones, 1999), their colonial and legal origin (Acemoglu et al. 2001, and la Porta et al., 2008) and their language and religious characteristics (Alesina et al. 2003).



Our results are once more extremely robust and support our hypothesis. On the other hand, however, since human capital data are quite persistent over time, the econometric literature suggests the use of different estimators capable of dealing with both the measurement error and the endogeneity of the regressors in a dynamic panel. We re-run our empirical model by applying the dynamic system GMM estimators proposed by Arellano and Bover (1995)<sup>8</sup>. In addition to this, we also correct for small sample biases by applying the two-step optimal estimation procedure proposed by Windmeijer (2005). Contrary to VAM's theoretical predictions and empirical results, our estimates are extremely robust and reveal the fundamental role played by skilled labor (as opposed to unskilled labor) in the economic growth of developing countries.

Interestingly, once endogeneity and identification issues are more adequately addressed, the estimated impact of tertiary education on the "catch-up" of developed countries is (somewhat puzzlingly) found to be negative.

We argue there are several possible reasons for this outcome. The main one is that, when approximating human capital by the average number of years of schooling we do not account for the quality of education, thereby inducing an underestimation of the impact of tertiary education, which potentially may be more severe at higher stages of development. Hanushek and Woessmann (2009) and Hanushek and Kimko (2000) argue, for example, that using the average number of years of schooling as a proxy for human capital may continue to hide the effect of differences in the quality of education systems across countries by imposing the same return to an additional year of education in, say, the US and Peru. The authors provide robust evidence of the statistical significance of cognitive skills (proxied by international achievement test scores) on economic growth, arguing that adjusting for the quality of education helps restore the (missing) positive relationship between human capital and economic growth.

Hence, here we also test whether the quality of education, rather than its quantity, has a statistically significant impact on economic growth and, crucially, if this impact differs for economies at different stages of development. Our results are strikingly robust to changes in the specification and to the data used and show that tertiary education (or high-quality education) is a fundamental driver of productivity and economic convergence in developing countries. When we adjust the average number of years of schooling proxies for quality of education, we also find a positive impact of tertiary education on the growth of developed countries even if, in keeping with our initial hypothesis, this effect is smaller the closer an economy lies to the technology frontier.

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<sup>8</sup> These estimators enable us to tackle simultaneity biases and to outperform LSDV and first-difference GMM estimators in the case of persistent explanatory variables, as is the case in our regressions.

Finally, we seek to provide a sound theoretical background to our results. Thus, we modify the Barro and Sala-i-Martin (1997) model so as to accommodate the assumption on human capital composition differences across countries (the North being at the technology frontier and the South lagging behind). The model is calibrated on empirical evidence so that the South is endowed with a relatively lower share of skilled workers in relation to its total population than the North. Differences in the quality of institutions are also accounted for in the model, while crucially we link the cost of innovation and imitation activities (respectively performed at the technological frontier and far away from it) to the human capital composition of each country (that is, to the relative ratios of skilled to unskilled workers). Solving for the model growth rates and calibrating the theoretical result on numerically plausible model parameters, we are able to show that a marginal increase in the share of skilled workers (tertiary or high-quality educated workers) boosts economic growth. Contrary to the findings of earlier theoretical models, the growth enhancing effect of an increase in the share of skilled workers is shown to be relatively greater the farther an economy lies from the technology frontier and the smaller its initial endowment of skilled workers.

The policy implications of our results are crucially different from those proposed elsewhere in the literature and suggest that pro-development policies should favor the accumulation of skills in technologically-lagging economies, despite the fact that these economies are producing low-technology goods and performing little or no innovation. In contrast to much of the previously mentioned literature, our results show that skilled labor has a crucial impact in those countries that are less endowed with this type of workforce (the developing countries) and that are currently struggling to catch-up with the technology frontier by means of technology imitation.

The rest of the paper is organized as follows. In section 2 we describe the data collection procedures and the data sources, while in section 3 we discuss our strategy for addressing endogeneity and simultaneity issues. In section 4 we present the empirical results obtained using different estimation techniques and the quantitative measures of human capital (average number of years of schooling and fractions of the workforce at each level of education). In section 5 we discuss the empirical estimates on both the human capital quantity and quality proxies. In section 6 we describe a simple theoretical model à la Barro and Sala-i-Martin (1997) which provides a firm grounding for our empirical results. Section 7 concludes.

## 2. Data

In building our dataset we combine information from seven different sources as well as from previous empirical literature. Our final dataset covers 88 countries (both developed and developing) for the period 1960-2000. For the GDP data, we turn to the Penn World Tables 6.1 provided by Heston, Summers and Aten (2002). Since capital stock data are not available in this database, a common solution is to build capital stock estimates by applying the Perpetual Inventory Method (PIM) to time series investment data. Even though the PIM is a well-established method in the empirical literature, it is not without its concerns. These relate to the possible measurement error in the initial capital stock year, which could arise if the investment data do not go back far enough in time<sup>9</sup>. In a recent study, Baier, Dwyer and Tamura (2006) build capital stock estimates by exploiting long investment time series (in some cases dating back to the 18<sup>th</sup> century) provided by B.R. Mitchell (1998a, b, c). Investment data prior to 1992 are measured using: (i) International Historical Statistics: The Americas 1750-1993, (ii) International Historical Statistics: Africa, Asia and Oceania 1750-1993 and (iii) International Historical Statistics: Europe 1750-1993<sup>10</sup> so that the measurement error on the initial capital stock condition is of no concern in these estimates. We follow VAM and denote Total Factor Productivity (TFP) as output per worker minus capital per worker times capital share<sup>11</sup> and compute the proximity to the technological frontier as the ratio of each country's TFP level to that of the US's<sup>12</sup>.

Due to the aim of our study, the treatment of human capital data is of crucial importance for our analysis. As argued earlier, (one of) the most common approximations of human capital relies on computing the average number of years of schooling<sup>13</sup> of the workforce in each country/period. Available datasets make use of data from the UNESCO Statistical Yearbook as well as those provided in the United Nations Demographic Yearbook. In principle, it is possible to categorize human capital datasets according to whether they make use of both census and enrollment data or only the latter. In the first group, which should be regarded as superior to the second for the

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<sup>9</sup> See Gollop and Jorgenson (1980), Jacob, Sharma and Grabowski (1997) and Caselli (2005).

<sup>10</sup> More recent investment data, dating from 1992, are provided by the World Development Indicators 2000.

<sup>11</sup> Our results are not affected by the choice of the empirical specification accounting for growth. Results are robust to the computation of the TFP as proposed in Hall and Jones (1999).

<sup>12</sup> Again results are robust to the definition of the TFP gap, when this is computed as the ratio of each country's TFP to the highest TFP recorded in each year. We also argue that our results are robust to the computation of "development specific" TFP gaps, computed as the ratio of each country's TFP to the highest TFP in each quartile of the distribution.

<sup>13</sup> See Kyriacou (1991), Lau, Jamisom and Louat (1991), Barro and Lee (1993) and Nehru, Swanson and Dubey (1995) as well as de la Fuente and Domenech (2001) and Cohen and Soto (2006). The last data source is used here.

richness of the information used, we find the human capital database of Barro and Lee (1993 and 1996), as well as the more recent data in the work of de la Fuente and Domenech (2001) and of Cohen and Soto (2001). In an interesting data comparison review, de la Fuente and Domenech (2006) show substantial measurement differences between the data proposed by de la Fuente and Domenech (2001) and Cohen and Soto (2006), on the one hand, and the widely used Barro and Lee (1993 and 1996) human capital series, on the other. De la Fuente and Domenech and Cohen and Soto's (2006) data are shown to perform better in panel data models due to the much smoother (and reasonable) dynamic behavior over time. As argued by de la Fuente and Domenech (2006) "the difference in the range of [annualized growth rate of average years of schooling] across data sets is enormous: while our annual growth rates range between 0.09% and 1.92% and those of Cohen and Soto between 0.27% and 3.27%, Barro and Lee's go from -1.35% to 6.13%; moreover, 19% of the observations in this last data set are negative, and 16.7% of them exceed 2%"<sup>14</sup>. Hence, due to the better quality and the larger sample size of the Cohen and Soto (2006) dataset<sup>15</sup> we opt to use this throughout our empirical analysis.

A further strand of literature (Hanushek and Kimko, 2000 and Hanushek and Woessmann, 2009) argues how the quality of education systems, rather than the "quantity" of formally completed education, represents a good (or better) approximation for human capital. It is argued, in fact, that using quantitative measures related to the number of years of schooling imposes the same returns to education in countries which differ greatly in the quality of their education systems and schools. This would eventually bias and drive the (lack of) results on the impact of human capital on economic growth.

Hanushek and Woessmann (2009) build a cross-country index of "cognitive skills" (available for 50 countries) which proxies for the average test scores in math and science of students (of primary through to the end of secondary school) in internationally comparable tests<sup>16</sup>. They provide compelling empirical evidence of the positive relation between average test scores and economic growth<sup>17</sup>, arguing for the crucial importance of adjusting standard measures of the average number of years of schooling for differences in the quality of education.

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<sup>14</sup> See de la Fuente and Domenech (2001).

<sup>15</sup> With respect to that used by de la Fuente and Domenech (2001) in which only OECD countries are available.

<sup>16</sup> Twelve waves of internationally comparable student achievement tests are included between the First International Mathematics Study (FIMS) in 1964 until the Programme for International Student Assessment (PISA) in 2003.

<sup>17</sup> In an earlier study, however, Pritchett (2001) challenges Hanushek and Kim's (1995) results suggesting that not correcting the average number of years of education proxies for differences in the quality of education cannot directly represent the cause of the widely observed negative effect of the average number of years of education on economic growth. Pritchett (2001), p. 379.

To this end, we use the internationally comparable test score index proposed by Hanushek and Woessmann (2009) to check the robustness of the results obtained using Cohen and Soto's (2006) quantitative education proxies. Thus, we build a new composite indicator which adjusts Cohen and Soto's (2006) number of years of schooling data for the differences in the quality of each country's educational system and we test the robustness of our hypothesis again with this new indicator.

Previous empirical literature has also examined economic growth and productivity convergence in relation to each country's institutional quality. Hall and Jones (1999), Acemoglu et al. (2001), Easterly and Levine (1997), Glaeser and Shleifer (2002), La Porta et al. (1999) and Rodrik et al. (2004) point to the crucial role played by institutional quality in economic growth, while Manca (2010) recently estimated the specific impact of different institutional arrangements on TFP "catch-up" across countries. The relationship between human capital and institutional quality has also been studied in a number of empirical studies. Following the suggestion made by Lipset (1960), Glaeser et al. (2004) revisited the debate over whether institutions cause economic growth or whether, better human capital leads to institutional improvement and then to long-run economic growth, arguing that "evidence suggests some skepticism about the viability of democracy in countries with low level of human capital". However, it could also be pointed out that high levels of human capital may extract lower-than-expected economic returns if the institutional framework is poor: "The incentives that are built into the institutional framework play the decisive role in shaping the kinds of skills and knowledge that pay off " (North, 1990). Education and institutions are evidently very much linked. In our analysis we proxy for institutions by using the Economic Freedom of the World panel dataset, which is itself based on survey data from two annual publications: the Global Competitiveness Report and the International Country Risk Guide. The index measures the degree of economic freedom between 1970 and 2000 in five major areas: (i) Size of Government: Expenditures, Taxes, and Enterprises, (ii) Legal Structure and Security of Property Rights, (iii) Access to Sound Money, (iv) Freedom to Trade Internationally and (v) Regulation of Credit, Labor, and Business. Within the five major areas, 21 components are incorporated into the index but many of those components are themselves made up of several sub-components<sup>18</sup>. In our analysis we use the chain-linked average index as a proxy for country specific institutional quality in each period. Institutions may, however, be potentially endogenous to economic growth. In order to instrument for institutions, we exploit country-specific and time-invariant characteristics in the same way as the instruments suggested by la Porta et al. (1998) on

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<sup>18</sup> If we count the various sub-components, the EFW index uses 38 distinct pieces of data.

the different legal origin of each country, the religious fractionalization proposed by Alesina et al. (2003) or a country's latitude, and the linguistic variables as in Hall and Jones (1999).

In Table 1 we present the descriptive statistics of the main variables of interest both for the whole sample and for the sub-samples of OECD and Developing countries. Summary statistics show the substantial differences between these two sub-samples. The average TFP proximity of the OECD sample with respect to the US's is 0.69<sup>19</sup> while it is only 0.22 for the sub-sample of Developing countries. As expected, there are also substantial differences in human capital endowment across countries, with the average number of years of tertiary schooling in OECD countries standing at 0.51 compared to 0.22 for the Developing countries sub-sample. Similarly, (as expected) the OECD countries are shown to have better institutions than developing economies.

[Table 1 about here]

### 3. Determinants of contagion

The empirical model that we test here is very much in the spirit of those proposed by VAM and by Benhabib and Spiegel (2005). Both empirical specifications are technology "catch-up" models, which assume that human capital proxies for the economy's technology absorptive capacity<sup>20</sup>. We consider the following empirical specification:

$$g_{i,t} = \beta_{0i} + \beta_1 a_{i,t-1} + \beta_2 e_{i,t-1} + \beta_3 a_{i,t-1} * e_{i,t-1} + \beta_4 z_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

where  $g_{i,t}$  is country  $i$ 's TFP growth rate,  $a_{i,t-1} = A_{i,t-1} / \bar{A}_{t-1}$  represents the follower's proximity to the technology frontier ( $\bar{A}$ ) in the previous period,  $e_{i,t-1}$  represents human capital which (depending on the specification) will proxy for the (i) fraction(s) of the workforce with a specific education attainment level (tertiary, secondary or primary), for (ii) the average number of years of schooling (in tertiary, secondary or primary), for (iii) the cognitive skill index (proxying for the quality of each

<sup>19</sup> The average TFP gap in VAM was slightly higher, 0.74.

<sup>20</sup> Unlike other empirical models that assume human capital to be a production factor which augments labor (Barro and Sala-i-Martin, 1995; Aghion and Howitt, 1992), both VAM and Benhabib and Spiegel assume that the effect of human capital enables lagging economies to "catch-up" with the frontier, thereby enhancing technology spillovers. As Benhabib and Spiegel (2005) point out "the policy implications of distinguishing between the role of education as a factor of production and a factor that facilitates technology diffusion are significant. In the former, the benefit of an increase in education is its marginal product. In the latter, because the level of education affects the growth rate of total factor productivity and output, its benefits will be measured in terms of the sum of its impact on all output levels in the future".

country's education system) or for (iv) the composite human capital index built adjusting (i) and (ii) for the differences in the quality of the education systems.

The term  $a_{i,t-1} * e_{i,t-1}$  represents the interaction of human capital with the TFP gap. The empirical model in (1) resembles that proposed by VAM and it only differs from Benhabib and Spiegel's (2005) logistic technology diffusion function in that we have introduced an additional term  $\beta_1 a_{i,t-1}$  which aims at controlling for "exogenous" TFP catch-up, independent of each country's human capital absorptive capacity. To both VAM and Benhabib and Spiegel's (2005) specifications we also add an extra covariate proxying for each economy's institutional quality,  $\beta_4 z_{i,t-1}$  as well as including time and continent dummies in all the econometric specifications.

The estimation of the empirical model in (1) poses a number of different challenges. The most critical of these is how to deal with the potential endogeneity of education with regard to economic growth, as pointed out by Bils and Klenow (2000). Instrumental variable techniques are a reasonable way to solve this endogeneity problem. For these, we need to find suitable instruments for our human capital proxy that must be uncorrelated to the error process and satisfactorily correlated to the endogenous variable. Moreover, in our specific case, these instruments have to be available for 88 developed and developing countries. Following VAM's suggestion we treat all right-hand side variables as endogenous and instrument them with their values lagged one period<sup>21</sup>. This applies also to the interaction term between human capital and proximity to the frontier, and to institutional quality. As for choosing among the available estimators that are able to cope with endogeneity, we initially run the model by applying both fixed-and random-effects instrumental variables and then test one empirical model against the other. The results and discussion of the best specification are given in the next section.

However, as Aghion et al. (2009) point out, the estimates carried out using IV panel data (either fixed or random effects) may still suffer from measurement and endogeneity problems owing to omitted variables that are highly correlated over time and within a country (i.e. institutions). On the one hand, in order to solve this problem (as well as to enrich the analysis) we introduce each country's institutional quality as an additional explanatory variable (as implicitly suggested by Aghion et al., 2009). Nonetheless, this might not yet be sufficient to tackle endogeneity fully.

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<sup>21</sup> In VAM the instruments are the explanatory variables lagged two periods rather than one. However, they use a five-year panel (as opposed to the ten-year panel that we use here) so that our lagged variables match their time span exactly. VAM are also able to exploit information on per capita spending in education as instruments which, however, is not available to us because of our larger sample size. However, they argue that their results for the OECD sample are unaffected by the use of this additional information.

An additional problem to the omitted variable bias is the fact that education variables, as well as institutions, are quite persistent over time. In this instance, it is well known that system GMM estimators for dynamic panel data models perform better than standard first-difference estimators (Arellano and Bond, 1991) while also allowing internally built instrumental sets to be exploited. Blundell and Bond (1998) show that when the endogenous variables considered are close to a random walk process the difference GMM estimators behave poorly because past levels of endogenous variables convey little information about future realizations.

Arellano-Bover(1995)/Blundell-Bond (1998) system GMM estimators allow us to build internal instrumental sets relying on the moment conditions produced by exploiting lagged realizations of the variables in the model (both dependent and exogenous/endogenous ones) and as such represent a drastic improvement on simpler OLS or LSDV estimators which, as shown in the literature (see Nickell, 1981; Kiviet, 1995 and Bond, 2002) might produce upward and downward biased coefficients respectively<sup>22</sup>. On the efficiency side, recent improvements in econometrics theory now allow us to apply the so-called "two-step" System GMM estimator. Unlike the "one-step" version, the two-step variant of the System GMM makes use of an "optimal" weighting matrix which is the inverse of the estimate of  $V ar[z_0]$ , where  $z$  is the instrument vector and " the error term. It is argued, however, that this optimal weighting matrix makes the two-step GMM asymptotically efficient albeit at the cost of producing severely downward biased standard errors (Arellano and Bond, 1991; Blundell and Bond, 1998). This problem is even more pronounced in the case of small samples and when the number of instruments is large. As Windmeijer (2005) and Roodman (2006) argue, the problem may be as severe as to make two-step GMM useless for inference. Thus, Windmeijer (2005)<sup>23</sup> proposes a correction to the two-step covariance matrix which, it is argued, can make the two-step robust estimation more efficient than the robust one-step especially for system GMM. Hence, we apply this modification of the system GMM estimator to the empirical model in (1), our preferred econometric model.

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<sup>22</sup> The so-called difference GMM estimator relies on the transformation of all regressors, usually by differencing them and, of course, it uses the Generalized Method of Moments (Hansen 1982) for estimation. The System GMM estimator, by contrast, relies on one additional assumption, i.e., that first differences of instruments are uncorrelated with the fixed effects thereby allowing the introduction of more instruments. This, as pointed out by Roodman (2006), can dramatically improve efficiency especially when, as in our case, the explanatory variables are likely to be persistent and to be weak instruments.

<sup>23</sup> As pointed out by Roodman (2006), "the usual formulas for coefficient standard errors in two-step GMM tend to be severely downward biased when the instrument count is high. Windmeijer (2005) argues that the source of trouble is that the standard formula for the variance of FEGMM is a function of the optimal weighting matrix  $S$  but treats that matrix as constant even though the matrix is derived from one-step results, which themselves have error. He performs a one-term Taylor expansion of the FEGMM formula with respect to the weighting matrix, and uses this to derive a fuller expression for the estimator's variance". The correction has been made available in STATA by Roodman (2006).



## 4. Estimation results

### 4.1. Panel instrumental variable estimation

In what follows we provide a wide variety of results based on the measures of human capital discussed above. Further, we test the empirical model in (1) by using different estimators and controls for endogeneity, as well as proposing different econometric models so as to accommodate both the VAM and the Benhabib and Spiegel (2005) specifications. All tests are then run on the whole sample and on the development-specific sub-samples.

As our starting point, we estimate VAM's empirical specification (human capital fractions) by using both "within groups" FE and RE instrumental variable estimators. We test the goodness of the fixed vs. the random-effect models under the null hypothesis that the individual effects are uncorrelated with the other regressors in the model (Hausman, 1978). The Hausman test (reported at the bottom of Table 2 below) does not reject the null hypothesis indicating that the random effects should be preferred over the fixed effects specification.

The Hausman statistics is run on different empirical models as a robustness check on the logistic diffusion function á la Benhabib and Spiegel and also when we use either fractions or the average number of years of schooling. The results<sup>24</sup> confirm that random-effects IV estimators are preferable to the fixed effects model in all the specifications analyzed.

[Table 2 about here]

Our results in Table 2 show the heterogeneous impact of different levels of education (expressed here by the fraction of the workforce aged 25 or more in tertiary, secondary or primary education) on the growth of countries at different stages of development. In columns (1) to (3) we report the results of the estimated impact of tertiary education on TFP "catch-up" for the whole sample as well as for the sub-samples of OECD and developing countries, while in the remaining columns we analyze the impact of secondary and primary education respectively.

The impact of tertiary education on growth is statistically significant and precisely estimated only for the developed countries sub-sample. The coefficient associated with the share of skilled workers (tertiary education) shows a positive coefficient estimated at one percent confidence

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<sup>24</sup> Not reported but available from the authors upon request.

level. Similarly, the interaction term between the TFP gap and human capital shows a strong and negative statistically significant coefficient indicating that technology catch-up is enhanced by larger shares of tertiary educated workers. The result is in line with our hypothesis on the crucial role played by skilled workers in economic convergence at lower stages of development.

When we examine the result for the OECD sub-sample, the coefficients associated with tertiary education and with the interaction term are, by contrast, somewhat imprecisely estimated and not statistically significant, while the proximity to the frontier term (TFP gap) shows the expected negative coefficient at five percent statistical significance level. Furthermore, institutional quality enters with a statistically significant and positive coefficient but only in the whole sample specification.

When we run the same model on secondary education (columns (4) to (6)) we find additional confirmation for the heterogeneity of the results when countries are analyzed at different stages of development. The estimated coefficients of secondary education and of its interaction with the TFP gap are statistically significant for the whole sample as well as for the developing countries sub-sample (while, once more being rather imprecisely estimated for the OECD sub-sample), pointing to the important role played by secondary education in TFP “catch-up”. Crucially, however, the magnitude of a marginal increase in tertiary education on growth is far greater than that of either secondary or primary education, indicating that increasingly higher levels of education lead to faster productivity convergence and that this effect is stronger the farther away an economy lies from the technology frontier and the smaller its initial skill endowment.

In interpreting these results, it is important to note that, since the model estimated in Table 2 relies on a specification in which the education proxies enter as fractions over the total workforce, the coefficients reported represent semi-elasticities. As Serrano (1997) suggests, it is possible to retrieve the values of the coefficients' implied elasticities by noticing that  $\gamma_{ed} = \beta * \partial h / \partial \theta_{ed} * \theta_{ed} / h$ , where  $\gamma$  represents the elasticity,  $\beta$  the estimated coefficient on the education fraction and  $\theta$  and  $h$  respectively the share of population within a certain education category (ed) and the number of years of schooling of that specific category. Crucially, note that when fractions are used as explanatory variables, the magnitude of the semi-elasticity coefficients are systematically downward biased with respect to their implied elasticities. Moreover, the bias that arises between the semi-elasticity and the implied true elasticity is greater, the smaller the fraction of population is in the category being examined<sup>25</sup>.

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<sup>25</sup> See Serrano (1997).

This implies that the differences in the impact on growth of tertiary, secondary or primary education are even greater than those reported by the semi-elasticities. A similar reasoning would apply if we wished to compare the magnitude of tertiary education's elasticities in the sub-samples of Developing and OECD countries, given the larger share of tertiary-educated workers in the latter.

The results presented above are robust to alternative empirical specifications. In Table 3 we test our hypothesis on a logistic diffusion function model. As Benhabib and Spiegel (2005) argue, there are both theoretical and empirical reasons for believing that an S-shaped diffusion function should be preferred to the (somewhat more widely used) confined exponential diffusion (see Banks, 1994 or Benhabib and Spiegel, 1994). The logistic formulation, in fact, "allows for a dampening of the diffusion process so that the gap between the leader and the follower can keep growing<sup>26</sup>" so that this formulation does not restrict the followers to grow at the speed of the leader from which they might also diverge in the long-run. This is particularly important when we analyze countries at very different stages of development since it allows us to account for the fact that the world technology frontier might not be immediately available to all followers (see Basu and Weil, 1998) and that a divergence pattern might arise as a result of it. The empirical results, however, confirm our hypothesis and are in line with those obtained in Table 2.

[Table 3 about here]

Both tertiary education and its interaction with the TFP gap are estimated as being statistically significant at one percent confidence level for the developing countries sub-sample. A similar result is now also recorded for the whole sample but, again, with a lower estimated coefficient. Secondary and primary education are also shown to have a positive, but relatively lower, impact on TFP convergence than tertiary education, indicating that it is the top margin of education (tertiary levels) that does most to speed up convergence.

Interestingly, the same results apply when, instead of using the OECD vs. Developing countries sub-samples we run quartile regressions for the top 25% of the GDP distribution (proxying for developed countries) vs. the bottom 75 or 50% (proxying for increasingly under-developed countries)<sup>27</sup>. The effect of tertiary education on growth becomes greater as the stage of

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<sup>26</sup> See Benhabib and Spiegel (2005).

<sup>27</sup> The results are available from the authors upon request.

development of the countries decreases, thereby confirming the stronger effect of tertiary education on “catch-up” as we move farther away from the frontier.

In line with VAM, we also analyze the impact on growth of the average number of years of education (in different educational categories) as an alternative to the human capital share proxies. To this end, we group human capital into two categories representing, on the one hand, average number of years of schooling in primary and secondary education and, on the other hand, average number of years of schooling in tertiary education<sup>28</sup>. The results are presented in Table 4 where we pool the different human capital proxies along with their interaction with the TFP gap and the initial gap alone as in VAM. To this specification, we then add institutional quality as an additional explanatory variable to check for the robustness of the results.

[Table 4 about here]

The results strongly confirm our initial hypothesis regarding the importance of tertiary education (as opposed to the weaker effect of primary and secondary education) for the “catch-up” of developing countries. The results are also robust to the introduction of institutional quality, which is, however, only significant for the whole sample. If we repeat the same exercise on the logistic diffusion model (reported in Table 5) the results are qualitatively the same with just a very minor change in the estimated elasticities of human capital proxies.

Somewhat surprisingly, the results in Table 4 show a negative impact of the average number of years of tertiary education on the growth of OECD countries. Our explanation of this result is twofold. On the one hand, part of the result might be driven by identification problems, as argued by Aghion et al. (2009), which would be exacerbated by the small number of observations available for the OECD sample. We address this point in the next section by applying system GMM estimators which, however, only partially restore the expected positive impact of tertiary education on growth for the OECD sample while leaving the other main results unaltered. On the other hand, however, the empirically weak significance of tertiary education for the “catch-up” of OECD countries may also be related to the way we approximate skills and education. As Hanushek and Woessmann (2009) claim, by using solely quantitative measures to proxy for human capital we may under or over-estimate the contribution of human capital to growth. It is our belief that this problem is more pronounced for developed than for developing countries. We show that, once we control for the quality of education, we are able to restore the expected

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<sup>28</sup> Similar results are, however, obtained when we disaggregate human capital into the average number of years of primary, secondary and tertiary schooling.

positive effect of tertiary education on the growth of the latter. We defer a more thorough analysis of these results, and a discussion of the arguments supporting this hypothesis, to section 5.

## 4.2. System GMM estimations

As argued in section 3, there are several reasons for believing that panel instrumental variable techniques may not be sufficient to fully tackle the endogeneity between education and growth. Therefore, we now turn to our preferred econometric model that exploits system GMM estimators and which is able to tackle measurement and endogeneity problems as well as the persistence of the human capital series. As before, we first analyze VAM's basic specification by using, as our explanatory variables, the fractions of tertiary, secondary and primary education and their interaction with the TFP gap.

[Table 6 about here]

The results in Table 6 once more support the heterogeneous effect of human capital composition on growth at different stages of development. The coefficient for tertiary education (fractions) and that of its interaction with the TFP gap show the expected signs for the developing countries' sub-sample and are estimated at five percent confidence levels<sup>29</sup>. Secondary education is also shown to have a positive impact on the growth of developing countries, but its impact is shown to be smaller than that of tertiary education. Indeed, the results for the OECD sub-sample are again in line with those reported above in Tables 4 and 5 for which tertiary (fractions) education shows a negative impact on productivity "catch-up". As VAM argue, however, the "occurrence of the IT revolution [may have had an] impact on the relationship between education and growth". We test this additional hypothesis by running the model for the post-1980 period only. The coefficients associated with tertiary education and its interaction with the TFP gap are not statistically different from zero for the OECD post-1980 sub-sample. By contrast, for the sub-sample of developing countries, along with the positive effect exerted by tertiary education on TFP "catch-up", the share of the tertiary-educated workforce is also statistically significant<sup>30</sup>. These results are presented in the appendix. Turning to the estimation of the logistic diffusion function á la Benhabib and Spiegel (2005) we once again find confirmation of the importance of tertiary education for the "catch-up" of developing countries. The results in Table 7 show the expected (highly) significant negative coefficient of the interaction term between tertiary education and the TFP gap for the sub-sample

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<sup>29</sup> The magnitude of the coefficients is, however, considerably lower if compared to the results of the IV estimations presented in the previous section, but it still points to the same qualitative results.

<sup>30</sup> Results are dependent on the introduction of differences in institutional quality across countries.

of developing countries, pointing to the faster convergence of countries that lie farther away from the frontier.

[Table 7 about here]

As for the OECD sub-sample, the interaction term between the tertiary-educated fraction and the TFP gap for the OECD countries is now statistically significant (but only at ten percent confidence level) and with a negative sign, pointing to the likely positive impact of tertiary education on growth.

Crucially, however, when we compare the magnitude of the catch-up effect across different stages of development, the effect of tertiary education on growth is once more shown to be much stronger at lower stages of development, as reported by the far larger coefficient of the interaction term for the sub-sample of developing countries.

A similar reasoning applies to the results for the specifications of secondary and primary education. Secondary education positively explains economic growth but with a relatively lower impact if compared to that of tertiary education at all stages of development. Our system GMM estimations are also robust when we proxy human capital composition by the average number of years of schooling in each education category. Here again, tertiary education exerts a positive and statistically significant impact on the growth of developing countries while it would seem to have a negative effect on the growth of developed countries.

[Table 8 about here]

As an additional check, in Table 9, we analyze tertiary and secondary education separately so as to compare their impact on growth at different stages of development. The results are unchanged.

[Table 9 about here]

Developing countries are found to be the ones that benefit the most from an increase in tertiary education. The results do not seem to be driven by any model misspecification or identification problem. As for the system GMM estimations, the robust Hansen over-identification tests on the joint significance of the instrumental set (built on the lagged levels and differences of the endogenous variables) do not reject the hypothesis regarding the goodness of the instruments.

The same applies to the test developed by Arellano and Bond (1998) aimed at checking for the presence of autocorrelation in the disturbance term which is passed in all specifications (including those presented in the earlier tables).

As discussed above, various institutional control variables have been introduced in all the specifications, as suggested by Aghion et al. (2009), with the twofold purpose of analyzing the impact of differences in institutions on growth and of overcoming the potential biases in the estimation when lagged realizations of human capital might be correlated with the quality of each country's institutions. From an econometric point of view, an advantage of system GMM over difference GMM estimators is the possibility of including time-invariant instruments in the system, which may help in the identification of endogenous variables and control for additional country-specific characteristics related to economic growth. Glaeser et al. (2004) claim that "Europeans brought their legal system into the countries that they conquered and colonized and that, therefore legal origin can be used as an instrument for the structure of various laws". Also, la Porta et al. (1998), in examining the relationship between the legal system and economic performance, argue that a country's legal origin can be viewed as an indicator of the relative quality and power of the government.

Similarly, various empirical studies (see, among others, Easterly and Levine (2002), Alesina et al. (2003, 2008), la Porta et al. (1998) and Landes (1998)) have reported the relationship between religion (and religious fractionalization) and economic development. Landes (1998) argues specifically that Catholic and Muslim countries "have tended to develop xenophobic cultures and powerful church/state bonds to maintain control, which hinders institutional and economic development<sup>31</sup>". Following the empirical strategy proposed in similar contexts by Acemoglu et al. (2001) and la Porta et al. (1998), we instrument institutional quality by legal origin (whether a country's legal origin is French, Scandinavian, British or German) and by the religious fractionalization of each country (proxied by the fraction of Catholic, Muslim, Protestant or neither of these in the total population).

The results reported in Tables 6 to 9 are hence robust to the introduction of all of these institutional controls<sup>32</sup>. Our results show that institutional quality is indeed an important driver of TFP growth in line with the empirical results reported elsewhere in the literature (see Hall and Jones, 1999 and Acemoglu et al., 2001). The elasticity associated with a one percent change in

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<sup>31</sup> See also Easterly and Levine (2002).

<sup>32</sup> As an additional check we also run the empirical model by directly introducing the religion and legal origin proxies as explanatory variables. Our results are unchanged and can be provided by the authors upon request.

institutions ranges between 0.09 and 0.15 percent of overall TFP growth, suggesting that countries with better institutional quality are indeed converging faster on the world technology frontier and increasing their productivity.

## 5. Quality of education (?)

Remarkably, our previous estimates show a negative (or statistically non significant) impact of tertiary education on the growth of OECD countries. This result appears (somewhat persistently) in almost all the specifications and merits discussion.

As we argued very briefly above, there are several reasons to believe that the estimated effect of tertiary education on the economic growth of OECD countries may prove to be null or negative.

On the one hand, a weak(er) effect of tertiary education on the growth of developed countries is consistent with evidence on international returns to investment in education estimated in various influential studies. Psacharopoulos (1994) and Psacharopoulos and Patrinos (2002) provide evidence of the heterogeneity of the returns to investment in different education levels across countries at different stages of development.

Psacharopoulos (1994) argues that "social and private returns largely decline by the level of a country's per capita income" and "the declining pattern of the returns to education is also observed over time". Interestingly, however, even larger differences can be detected when we specifically look at the returns to each education level. Returns to primary education, estimated using the standard Mincer (1974) wage equation, are shown to be quite homogeneous across very different stages of development. Estimated private returns to investment in primary education, for instance, range between 25.6 percent for the high-income group (\$9,266 or more) to 27.4 percent for the middle income (up to \$9,265) and 25.8 percent for low income countries (less than \$755)<sup>33</sup>. This picture is extremely different, however, when we look at the estimated returns to secondary and tertiary education. Low income countries show the highest returns to both secondary and tertiary education while high-income countries experience the lowest returns. More specifically, the returns to secondary education range between 12.2 percent for the high income sample to 18.0 and 19.9 percent for the middle and low income samples respectively. Even more striking, the estimated returns to secondary education are quite similar to those of tertiary education within each income group with the exception of the low income sub-sample which, by contrast, shows much higher returns to tertiary than to secondary education. In the

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<sup>33</sup> See Psacharopoulos and Patrinos (2002).



high-income sample, for instance, the estimated returns to secondary education (12.2 percent) are in line with those to tertiary education (12.4 percent) while in the low income sample a substantial difference in returns between secondary (19.9 percent) and tertiary education (26.0 percent) is experienced.

This evidence pinpoints the specific role played by tertiary (and, in part, by secondary) education in the growth of developing countries. The heterogeneity in the returns of tertiary education at different stages of development might explain, at least in part, the weak impact of tertiary education on the “catch-up” of advanced economies and corroborate our strong results for the developing countries. However, together with this evidence, we believe that another crucial issue plays a (joint) role in the explanation of the weak relationship between economic growth and tertiary education in developed countries. As Hanushek and Woessmann (2009) argue, the typical proxies used to account for cross-country differences in human capital do not account for the differences in the quality of the human capital but rather only for their relative quantity. Hence, they argue that the raw number (quantity) of graduate students in each economy may not properly signal the skill intensity of the workforce and that this would lead to the underestimating of the role of tertiary education in the “catch-up” of developed countries in particular.

Crucially, in fact, the “human capital quantity-signaling” bias may be more severe in developed than in developing countries once we acknowledge the fact that access to tertiary education in OECD countries has steadily increased over time and that access to, and completion of, tertiary education is relatively much easier in the OECD countries than in less developed regions of the world.

As Hanushek and Zhang (2009) argue, “the school and college selectivity has gone down over time [...] if school continuation is related to ability, people with lower innate ability on average have been promoted to greater schooling levels over time” and “if so, contributions of more recent cohorts’ schooling will be underestimated”<sup>34</sup>. Indeed, if we examine our sample, the difference between the tertiary enrollment rates of OECD and developing countries has been steadily rising (rather than falling) over recent decades. The average share of tertiary-educated workers in the OECD countries grew from 0.05 in 1960 to an average of 0.19 percent in 2000. By contrast, the share of tertiary-educated workforce in developing countries grew from an initial value of 0.01 percent in 1960 to 0.06 in the year 2000, thereby diverging from the OECD’s tertiary growth path.

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<sup>34</sup> See Hanushek and Zhang (2009).

If anything, therefore, it would appear that having completed tertiary education is likely to "signal" less about the workforce's "true" human capital in OECD countries than it does in developing countries simply because access to tertiary education in OECD countries is far more universal, increasingly allowing less talented students to complete their tertiary education.

In developing countries, by contrast, access to and completion of tertiary education is likely to give stronger indications of the skills of the average tertiary-educated worker with regard to the average human capital of the population, due to the relatively stricter entrance procedures into tertiary education.

Indeed, if we investigate the relationship between quantity-based human capital measures (average number of years of schooling or fractions of tertiary-educated workers) and quality-based measures as proposed by Hanushek and Woessmann (2009), a positive and statistically significant correlation emerges when we regress international test score achievements in math and science (proxying for the quality of education) on the quantitative measures of tertiary education.

This positive and statistically significant relationship is found, however, only for developing countries, while a negative but non significant relation is found for OECD countries when we also control for cross-country differences in institutional quality<sup>35</sup>. Far from constituting sound empirical proof, this simple test (along with the empirical evidence of decreasing returns to tertiary education/stage of development) hints at the validity of the hypothesis that the human capital signaling bias might be stronger at higher stages of development and that this may be one of the causes of the weak coefficient associated with the average number of years of tertiary schooling estimated for OECD countries<sup>36</sup>.

Conversely, it also suggests that the results obtained for developing countries are, by contrast, likely to be confirmed when we adjust the human capital proxies for the quality of the education systems. Hanushek and Woessmann (2009) provide two indexes for a cross-section of 50

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<sup>35</sup> Results are presented in the appendix.

<sup>36</sup> Following a similar line of reasoning, Gary Becker and Richard Posner in their blog argue that, for developed countries, "there probably are diminishing returns to providing higher education, because IQ provides a ceiling beyond which educational effort is wasted on students. The United States may be in that position today. Many colleges offer what amounts to a remedial high school education, postponing the students' entry into the work force. If we had better high schools, we might have fewer colleges (or more - if better high schools improved intellectual motivation and performance). With ever-increasing specialization of the workforce, there is an argument for making education increasingly vocational.

developed and developing countries that proxy for the quality of education. The "cognitive skill index" refers to the average score in math and science of students who took internationally comparable tests between 1963 and 2003. The "top skills index" refers to the scores of only the top-performing students for the same time period. The correlation between the two indexes is high (0.73) and the regression results below are qualitatively very similar<sup>37</sup>.

The data provided by Hanushek and Woessmann (2009) proxy for the quality of the education systems and, in principle, allow us to compare the quality of education and human capital across countries. Indeed, as the authors state, "variations in cognitive skills can arise from various influences - families, culture, health and ability". This said, the authors also claim to be able to provide robust evidence that schools are one of the main channels affecting and shaping the quality of education outcomes in each country. It is interesting to note that the quantitative and qualitative human capital measures do convey information that is quite distinct<sup>38</sup>.

Of the top ten countries in terms of the highest average number of tertiary years of schooling, nine belong to the OECD sub-sample. However, when we examine student performances (education quality, cognitive skills) only six OECD countries enter the top-ten ranking. If, instead, we examine the developing countries sub-sample, smaller differences in the rankings are observed<sup>39</sup>.

When we cross this information with GDP per worker, a negative relationship emerges between quality of education and GDP per worker at high levels of development while, conversely, the relation between the quantity of tertiary education and GDP per worker is slightly positive at higher levels of development. If instead we focus solely on the ten best-performing developing countries, the relationship between human capital quality (cognitive skills) and development is (weakly) positive and the same is found for the relationship between years of tertiary schooling and GDP per worker<sup>40</sup>.

[Figure 1 about here]

[Figure 2 about here]

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<sup>37</sup> Results can be provided by the authors upon request.

<sup>38</sup> The overall correlation index between the quantitative and qualitative human capital indexes is 0.53.

<sup>39</sup> Of the ten countries with the highest average number of years of tertiary schooling, only five are also present in the ranking of countries with the highest cognitive skills.

<sup>40</sup> This further confirms that the potential bias between the quantitative and qualitative measures of human capital might be stronger for OECD countries than for their developing counterparts, as suggested above.

As an initial test on the impact of education quality on TFP “catch-up” we regress TFP growth on the cognitive skills index and its interaction with the TFP gap, as well as on institutional quality differences. The results are presented in Table 10.

[Table 10 about here]

As expected, the quality of education plays a fundamental role in growth at all stages of development. The interaction term’s coefficient is statistically significant for all the different development sub-samples, indicating that increasing the quality of education leads to a faster “catch-up” with the world technology frontier. Crucially, however, the magnitude of the effect is highly heterogeneous as in our previous results. Developing countries are shown to be the ones that benefit most from a marginal increase in the quality of education, with a coefficient which is almost twice that estimated for OECD countries. Endogeneity between quality of education and growth might, once again, be affecting these estimates. We employ both robust OLS estimators (in columns (1) to (3)) and the two-step efficient generalized method of moments (GMM) estimator to address endogeneity issues (in columns (4) to (6)). Due to cross-country comparability, the cognitive skill index is only available as an average over the period examined so that we cannot directly instrument it with lagged realizations in the GMM estimations. Instead, we use past realizations of the average number of tertiary years of schooling variable which, however, lead to a poor identification of the whole sample and the OECD sub-sample, as detected by the Kleibergen and Paap (2006) instrumental test<sup>41</sup>. The results are, however, satisfactory for the sub-sample of developing countries with an average bias of the IV estimator of less than 10 percent with respect to the OLS estimation.

That said, it is not only the quality of education that matters for growth but also the quantity. In Table 11 we regress the average growth of TFP over the period on our quality-adjusted measure of human capital (which interacts the cognitive skill index<sup>42</sup> with the human capital quantity measures), on its interaction with TFP and on institutional quality as an additional control variable.

As for previous estimations, we acknowledge the likely presence of simultaneity issues in the OLS estimations and re-run our test by implementing the two-step efficient generalized method of moments (GMM) estimator in the last three columns of Table 11.

[Table 11 about here]

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<sup>41</sup> Our results improve only slightly when we also instrument by per capita spending in education.

<sup>42</sup> Empirical tests have also been run on the top skill index and its interaction with TFP. Results are available from the authors upon request.

Once again, the magnitude of the impact of human capital (quality-adjusted) is quite heterogeneous across countries at different stages of development. Interestingly, the effect of human capital is positive (negative in the coefficient associated with the interaction term) for all countries and, hence, for the OECD sub-sample as well at the one percent confidence level in the GMM estimation. This is in contrast with the results based solely on quantitative measures of human capital. Crucially, therefore, on the one hand, our quality-adjusted human capital measure restores the expected positive role of tertiary education on the growth of all countries while, on the other, the magnitude of the “catch-up” impact on OECD countries is still between four and five times smaller than that for developing countries.

The results confirm our initial assumptions regarding the key role played by tertiary education in the “catch-up” of developing countries. As for the two-step GMM estimation, both institutions and human capital are assumed to be endogenous variables and are hence jointly instrumented in all the IV estimations. In the case of the (over)-identification of very different sub-samples of countries, this required the careful selection of the most suitable instruments. The instruments need to be highly correlated to the two endogenous variables being capable, at the same time, of conveying information about the relative differences within more or less homogenous sub-groups of countries as well as across very different development stages. On the one hand, we employ a common set of instruments for both sub-samples of OECD and developing countries so as to be able to draw meaningful comparisons across different stages of development and sub-samples. To do so, once more we resort to the use of the legal origin and religious fractionalization indexes employed in the GMM estimations above.

However, the over-identification of the (homogenous) institutions within the OECD sub-sample calls for the use of additional information. Hence, to the OECD instrumental set, we add the logarithm of the Frankel and Romer predicted trade shares<sup>43</sup> and the Government Anti-Diversion Policy (GADP)<sup>44</sup> index proposed by Hall and Jones (1999). As for human capital, we instrument this with the average per capita expenditure on education<sup>45</sup> and, when these data were unavailable, with the lagged average number of years of tertiary schooling. Overall, the Hansen over-identification test is passed for all specifications, pointing to the joint significance of our instruments. However, as Stock, Wright and Yogo (2002) point out, weak instruments may still be

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<sup>43</sup> The log predicted trade share of an economy is based on a gravity model of international trade that only uses a country's population and geographical features and for this reason can be treated as an exogenous instrument (see Hall and Jones, 1999).

<sup>44</sup> The GADP index is an equal-weighted average of the following sub-indicators: (i) law and order (ii) bureaucratic quality and, three categories related to the government's possible role as a diverter: (iii) corruption, (iv) risk of expropriation, and (v) government repudiation of contracts.

<sup>45</sup> These data are taken from the UNESCO statistical yearbook (1999).

a problem if their "relevance" to the endogenous variable(s) is only scarce. This problem is exacerbated when more than one endogenous regressor is jointly analyzed, thereby resulting in weak identification. This may well be our case here, since both human capital and institutions are treated as endogenous variables.

We control for this problem by applying the generalized weak identification Wald statistics proposed by Kleibergen and Paap (2006), which have the advantage over Cragg and Donald's (1993) F-tests of being valid to non-i.i.d. errors. Our statistics confirm the validity of the instrumental set used. Both in the case of the OECD and the developing country sub-samples the reported F-statistics confirm that the bias of the estimation performed by GMM using the proposed instrumental set is no more than, respectively, 5 and 10 percent of the inconsistency of an OLS estimation.

As an additional robustness check for these results, we also correct the average number of years of schooling for human capital quality and re-run the estimations. Once again the interaction term between human capital and the TFP gap shows a statistically significant coefficient in all specifications as well as when we control for endogeneity using two-step efficient GMM estimators.

Likewise, the difference in the magnitude of the effect of human capital on the "catch-up" is very similar to our previous results, highlighting the stronger effect of tertiary education on the growth of countries farther away from the technology frontier.

[Table 12 about here]

Overall, our results confirm the validity of the hypothesis according to which tertiary education (either raw-quantity or quality-adjusted measured) heterogeneously affects the "catch-up" of countries at different stages of development by benefiting most those that lie farthest away from the frontier and whose initial stock of highly skilled workers is relatively lower.

## 6. Theoretical background

### 6.1. Model's hypotheses

This section seeks to forward a technology catch-up model capable of theoretically grounding the empirical results obtained in the sections above and of illustrating the links and dynamics between human capital composition, stage of development, institutional quality, economic growth and catch-up. A natural option is to turn to the very well-established theoretical framework proposed by Barro and Sala-i-Martin (1997) and to augment it so as to accommodate the new assumption regarding the heterogeneity of human capital types (human capital composition) and to capture their links with technology imitation and innovation at different stages of development.

The theoretical model proposed here is similar to VAM's but it is grounded on a very different hypothesis regarding the way technology imitation might be linked to human capital composition. VAM's theoretical results are generated from the assumption that as imitation is relatively easier to implement than innovation, it is likely to be better performed by unskilled as opposed to skilled workers.

However, on the contrary, we believe there is no justification for the claim that unskilled workers will outperform their skilled counterparts, also (or especially), when it comes to innovating or imitating. As Maskus (2000) argues, technology imitation usually takes the form of adapting existing technologies to new markets. In order to adopt a new product (or a process), the follower usually needs to adapt the new technology to its market or productive needs. Managerial and technical skills are important, for instance, when the follower has to choose which innovation (from among a large pool of possibilities) should be implemented and adopted.

The profitability of the adoption then will be a function of the follower's judgment of the innovation's market potential as well as of the capabilities of workers of adopting the new technologies. This basic assumption regarding the costliness of technology adoption is very much in line with the theoretical framework forwarded by Nelson and Phelps (1966) who claim that "it is clear that the farmer with a relatively high level of education has tended to adopt productive innovations earlier than the farmer with relatively little education [...] for he is better able to discriminate between promising and unpromising ideas [...] The less educated farmer, for whom the information in technical journals means less, is prudent to delay the introduction of a new technique until he has concrete evidence of its profitability".

## 6.2. Model set-up

We assume that the world consists of two countries denoted by  $i=1,2$  where country 1 represents the North and country 2 the South. The output in the two countries is expressed by means of a Spence (1976)/Dixit and Stiglitz (1977) production function as follows:

$$Y_i = A_i (L_{yi})^{1-\alpha} \sum_{j=1}^{N_i} (x_{ij})^\alpha \quad (2)$$

$Y_i$  is output and  $x_{ij}$  is the quantity of the  $j$ th nondurable intermediate good used in the production by country  $i$ .  $N_i$  is the number of types of intermediates available (known) in country  $i$ . The variable  $N_i$  proxies for the technological level of country  $i$ . The technology shown in eq. (2) can be accessed by all agents in country  $i$  and production occurs under competitive conditions.  $A_i$  represents institutional quality<sup>46</sup> of country  $i$ . Following the empirical evidence, we assume that the North is endowed with better institutions than the South as follows:

$$A_1 > A_2 \quad (3)$$

$L_{yi}$  is the fraction of the labor force employed in the production of output  $Y_i$ <sup>47</sup>.

### 6.2.1 Human capital composition

We assume that labor in the two countries is heterogeneous in terms of their respective skill endowment. In both countries a fraction of the population will be of the low skill type, namely  $L_{yi}$ , and employed in the production of the final good  $Y_i$ . The remaining fraction of the workforce, namely  $L_{ri}$ , represents the high skilled workers that will be employed in the innovation or imitation activities of countries 1 and 2. The following general condition is hence satisfied:

<sup>46</sup> Some authors, including Keefer and Knack (2002), Alesina et al. (1992) and Levine and Renelt (1991) point to the process of democratization and the political stability of a country as the main features of its institutional quality. Others, such as Mauro (1995) and Barro (2000) similarly emphasize the role of corruption and criminality as distortions to the correct functioning of a country's institutional framework.

<sup>47</sup> Trade in final goods is assumed to be balanced between the two countries so that the domestic output is equal to the total of domestic expenditure destined for the consumption of goods,  $C_i$ , production of intermediates,  $X_{ji}$ , and R&D aimed at discovering new blueprints and varieties of intermediates. Since final goods are tradable internationally, market size does not influence the results. This setting is very similar to that proposed by Barro and Sala-i-Martin (1997).



$$L_i = L_{yi} + L_{ri} \quad (4)$$

where  $L_i$  is the total workforce. Noticeably, North and South differ in the composition of their human capital stocks. The North, consistent with the empirical evidence reported in Table 1, is populated by a relatively larger share of high skilled workers (as a proportion of its total population) than the South.

Conversely, the South, is largely populated by low skilled workers and only a relatively small fraction of its total workforce is of the high skill type. This condition can be restated more formally as follows:

$$L_{r1} > L_{r2} \text{ and } L_{y1} < L_{y2} \quad (5)$$

### 6.3. The leader country

We assume the North to be the technological leader. This is implied by the following:

$$N_1(0) > N_2(0) \quad (6)$$

where the pool of blueprints (or intermediates) that are known in country 1 is strictly higher than that in the technological follower country 2. The relative technological proximity between country 2 and country 1 is expressed by the following ratio:

$$0 < N_2 / N_1 \leq 1 \quad (7)$$

Throughout the rest of the paper we will be using the measure in eq. (7) to define the relative stage of development of country 2 with respect to that of the leader<sup>48</sup>.

One of the crucial assumptions of our formalization is that both innovation and imitation/adaptation are skill-costly activities. Hence, instead of assuming a fixed cost for innovation, as in Barro and Sala-i-Martin (1997), we assume, somewhat more realistically, that the cost of inventing a new blueprint, namely  $\eta_i$ , is a decreasing function of the fraction of workforce endowed with high skills within each economy. This assumption reads as follows:

$$\eta_i = \psi(L_{ri})^{-1} \quad (8)$$

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<sup>48</sup> Empirically, this would proxy for the TFP gap of the followers to the technology frontier.

Notice that the combination of eq. (8) with eq. (5) implies the following:

$$\eta_2 \geq \eta_1 \quad (9)$$

The different composition of human capital stocks in the two countries shapes their relative innovation possibilities<sup>49</sup>. The country endowed with a higher fraction of highly skilled labor becomes relatively more efficient at innovating due to the better educated and talented researchers employed in its R&D sector. Interestingly, this result is shared with VAM's formalization. In what follows, however, we will show that the assumption that highly-skilled workers innovate more efficiently than unskilled workers does not necessarily imply the opposite, i.e., that unskilled workers will imitate better than skilled workers.

### 6.3.1 Innovation production in the leader country

When a new intermediate good is introduced (invented) in country 1, the innovator retains monopoly power over the use of this good for production within country 1<sup>50</sup>. Since the intermediate good  $j$  is priced in country 1 at  $P_{1j}$  the flow of monopoly profit to the inventor is given by:

$$\pi_{1j} = (P_{1j} - 1)X_{1j} \quad (10)$$

where the 1 inside the brackets represents the marginal cost of producing the intermediate  $X_{1j}$ . The marginal product of the  $j$ th intermediate is given by :

$$\partial Y_1 / \partial X_{1j} = A_1 \alpha L_{y1}^{1-\alpha} (X_{1j})^{\alpha-1} \quad (11)$$

This, in turns, leads to the demand function for the intermediate  $j$  from all producers of goods in country 1:

$$X_{1j} = L_{y1} (A_1 \alpha / P_{1j})^{1/1-\alpha} \quad (12)$$

Substituting eq.(12) into eq.(10) we obtain the monopoly price, which is the same for all types of intermediates:

<sup>49</sup> We assume here, for simplicity, that is a linear function. This may not be the case, however, and more complexity may be added to the model by assuming a non-linear relationship between the cost of innovation and the share of skilled workers employed in R&D. The results will not change qualitatively.

<sup>50</sup> As pointed out by Barro and Sala-i-Martin (1997), it is however relatively straightforward to allow the good to become competitive with an exogenous probability  $p$  per unit of time.

$$P_{1j} = P_1 = 1/\alpha > 1 \quad (13)$$

which in turn implies that the total quantity of the jth intermediate that country i will be producing amounts to the following:

$$X_{1j} = X_1 = L_{y1}(A_1)^{1/1-\alpha} \alpha^{2/1-\alpha} \quad (14)$$

From this we eventually obtain country 1's total output by substituting eq.(14) into eq.(2) which gives:

$$Y_1 = A_1^{1/1-\alpha} \alpha^{2/1-\alpha} L_{y1} N_1 \quad (15)$$

By substituting eq.(13) and eq.(14) into eq.(10) we can obtain the flow of monopoly profit from sales to the owner of the rights of intermediate j as follows:

$$\pi_{1j} = \pi_1 = (1-\alpha)L_{y1}A_1^{1/1-\alpha} \alpha^{(1+\alpha)/(1-\alpha)} \quad (16)$$

As Barro and Sala-i-Martin (1997) argue, the present value of profits for the jth innovator is simply  $\pi_{1j}/r_1$  where  $r_1$  is the rate of return in country 1.

When free entry is assumed into the R&D sector (and the quantity of R&D is nonzero) it must be that the present value of profits equals the constant cost of invention  $\eta_1$  at each point in time. Hence, rearrangement of the free-entry condition implies the following rate of return for economy 1:

$$r_1 = (L_{y1} / \eta_1) \left( \frac{1-\alpha}{\alpha} \right) A_1^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} = \pi_1 / \eta_1 \quad (17)$$

where the rate of return  $r_1$  is the ratio of  $\pi_1$ , the flow of monopoly profit given in eq.(16), to the cost  $\eta_1$  of obtaining this profit flow. We assume that consumers maximize utility over infinite horizons through a standard Ramsey type utility function as follows:

$$U_1 = \int_0^{\infty} e^{-\rho t} \left[ (C^{1-\theta} - 1) / (1-\theta) \right] dt \quad (18)$$

where, as usual  $\rho > 0$  represents the rate of time preference and  $\theta > 0$  the magnitude of the elasticity of the marginal utility of consumption<sup>51</sup>. If we maximize the utility function subject to a standard budget constraint we obtain the usual expression for the consumption growth rate:

$$\dot{C}_1 / C_1 = (1/\theta)(r_1 - \rho) \quad (19)$$

The growth rate of  $C_1$  is constant due to the constancy of  $r_1$  as in eq.(17). Hence, the growth rate of the leader economy is given by:

$$\gamma_1 = (1/\theta)(\pi_1 / \eta_1 - \rho) = \left[ (1-\alpha)L_{y1}A_1^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}\eta_1^{-1} - \rho \right] \quad (20)$$

where the parameters of the model are such that  $\pi_1 / \eta_1 \geq \rho$  ensures positive growth. As expected, inspection of eq.(20) reveals that the growth rate of the leader is a positive function of institutional quality and of its human capital composition.

#### 6.4. The follower country

As argued above, the skill-costliness of technology imitation is widely observed and acknowledged in the theoretical and empirical literature alike. Here, we build on this body of literature and express the cost function of technology adoption as a function of the follower's skills and of its development stage:

$$v_2 = \psi(L_{r2})^{-1}(N_2 / N_1) \quad (21)$$

where  $v_2$ , represents the cost of adopting and correctly implementing a new technology in the follower country. The technology adoption cost,  $v_2$ , is assumed to be a negative function of the skill intensity of the South, that is of  $L_{r2}$ . Crucially, if two followers stood at equal distances from the frontier (at the same stage of development), the one endowed with a larger share of skilled workforce would be able to better distinguish between profitable and unprofitable technologies, to make better use of those profitable technologies in the production chain, to perform better and more efficient reverse engineering and, ultimately, to face a relatively lower cost of adoption,

<sup>51</sup> This implies that the intertemporal elasticity of substitution is equal to  $1/\theta$ :

leading it eventually to catch up with the frontier at a faster speed than the country endowed with relatively lower skills.

The cost of technology adoption is also linked to the relative distance from the frontier. In line with Connolly and Valderrama (2005) and Barro and Sala-i-Martin (1997), we assume this cost to be an increasing function of the proximity of the imitator with respect to the technological frontier so that, when there is a large pool of innovations (blueprints) that an imitator can copy, the cost of imitation tends to be low and vice versa.

In keeping with Barro and Sala-i-Martin's (1997) original model, once a new technology is discovered at the frontier it will be potentially available for adoption by the follower<sup>52</sup>. Assuming that consumers in the South maximize a similar Ramsey-type utility function as in the leader country, and solving for the stream of profit to the adopter, we can define the growth rate for the follower region as a function of its human capital composition through the parameters  $L_{y2}$  and  $\nu_2$  and of institutional quality,  $A_2$ . The equation leading to the solution for the growth rate of the follower are symmetric to that of the leader from eq. (10) to (20), so that we can express its growth rate as follows:

$$\gamma_2 = (1/\theta)(\pi_2/\eta_2 - \rho) = \left[ (1-\alpha)L_{y2}A_2^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}\nu_2^{-1} - \rho \right] \quad (22)$$

As we can see from eq.(22), the growth rate of the follower is closely linked to the composition of its human capital. More specifically, the follower's engine of growth lies in its technology absorptive capacity, that is, in its ability to receive the technology spillovers originating at the frontier. The crucial parameter is, in fact,  $\nu_2$ , the cost of technology adoption, which enters at the denominator of the expression in eq.(22). It is easy to recall that the cost of adoption is, itself, a negative function of the skilled fraction of the workforce as in eq.(21) so that an increase in  $L_{r2}$  will boost the capacity of the follower to adopt technology (reducing the adoption cost) but, at the same time reducing the share of workforce employed in the physical production of the final imitated good  $L_{y2}$ . This latter effect is however compensated by the former under general conditions and, especially, at lower stages of development or when the initial skill endowment of

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<sup>52</sup> For the sake of greater realism we assume the follower faces a fixed (but relatively negligible) cost, when acquiring the license to use the inventor's idea. This is, for example, the cost paid to the innovator for licensing, using or adapting his/her idea in the follower's market. Hence, once the idea has been made available to the adopter, the speed and ability of each follower/adopter to implement and make profitable the new technology varies as a function of their skills as in eq.(21)

the followers is relatively low. This outcome of this scenario is analyzed in the following proposition.

**Proposition 1:** A marginal increase in the share of the workforce with a higher level of education ( $L_{r2}$ , skilled workers) is growth enhancing for the followers, reducing the cost of technology adoption. Conversely, a rise in the fraction of population with low skills is shown to be growth diminishing and to lead to slower technology convergence. The result (which depends on the relative composition of human capital in the follower economy) is stronger the farther away the follower economy is from the technology frontier and the smaller the initial share of skilled workers.

**Proof.** The results follow the examination of the partial derivative of eq. (22) with regard to  $L_{r2}$  and its numerical calibration. Taking the partial derivative of the growth rate in eq.(22) with regard to  $L_{r2}$  and imposing this as being greater than zero yields the following expression:

$$\frac{\partial \gamma_2}{\partial L_{r2}} = \frac{1}{N_2 \theta} (L_{r2} N_1 \alpha - L_{r2} N_1) X + (N_1 - L_{r2} N_1 - N_1 \alpha + L_{r2} N_1 \alpha) X > 0 \quad (23)$$

where  $A_2^{\frac{1}{1-\alpha}} \alpha^{\frac{\alpha+1}{1-\alpha}} = X$ . It can be readily shown that, following the standard assumptions made regarding the model parameters for ensuring positive growth, the term  $(1/\theta)[(1-\alpha)L_{y2}A_2^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}v_2^{-1} - \rho]$  will always be greater than zero leading to the following simplification of  $\partial \gamma_2 / \partial L_{r2} > 0 \Leftrightarrow L_{r2} < 1/2$ . Hence, as long as the share of skilled workers is less than the average workforce, a marginal increase in the top margin skill will be growth beneficial. In order to grasp the magnitude of a marginal increase in  $L_{r2}$  on growth, and since eq.(23) is somewhat complex, we explicitly calibrate its parameters and solve it numerically in Figure 3 below.

[Figure 3 about here]

Our numerical simulation reports the impact of a marginal increase in  $L_{r2}$  for different scenarios of the initial levels of the share of skilled workers (0.3 and 0.35) and at different stages of development. In Figure 3 we plot the solutions for  $\partial \gamma_2 / \partial L_{r2}$  against increasing values of the proximity to the technology frontier. Larger positive effects of a marginal increase in  $L_{r2}$  are experienced when farther away from the frontier as argued in proposition 1. Similarly, when

holding constant the distance from the frontier, a marginal increase in  $L_{r2}$  has a greater impact when the initial values of the skilled workforce are smaller. In both cases, the theoretical predictions and the results of the numerical calibration of our modified growth model match the empirical evidence presented in previous sections.

Developing countries (those farthest away from the frontier and endowed with relatively smaller fractions of skilled workers) experience the largest marginal effect of an increase in tertiary education on growth. Conversely, countries endowed with relatively larger shares of skilled workers (the OECD countries for instance) experience smaller (and diminishing) returns to the change in tertiary education.

## 7. Conclusions

Our study provides compelling, robust evidence of the heterogeneous impact of human capital composition on the economic growth of countries at different stages of development. Tertiary education is shown to be the engine of productivity convergence at all development stages, while secondary and, especially, primary education are only marginally related to economic growth.

More importantly, and in contrast to the earlier theoretical and empirical literature<sup>53</sup> which argued for the "primacy" of high skills at higher stages of development, our results show that tertiary education is fundamental, especially, for the growth of developing countries, while its impact on developed economies is shown to be substantially weaker.

The policy implications that stem from these findings suggest that pro-development policies should seek to foster the accumulation of high skills, especially in the technologically underdeveloped countries and, contrary to common wisdom, independently of the fact that these economies might initially produce low(er)-technology goods or perform technology imitation. The effect of tertiary education on the rate of productivity growth and technology convergence is, in fact, shown to be substantially larger in developing countries than in their developed counterparts.

It is our belief that our empirical evidence supersedes that of earlier studies that have examined these issues from a variety of angles. In order to test the impact of diverse levels of education on the growth of economies at very different stages of development we built a large panel database, comprising 88 developed and developing countries for the years 1960 to 2000, by combining

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<sup>53</sup> See Vandenbussche, Aghion and Meghir (2006), Acemoglu and Zilibotti (2001) and Aghion et al. (2009) among others.

information from several sources. Previous studies, by contrast, have tended to focus on smaller samples and have, therefore, been unable to provide comprehensive evidence of the impact of different levels of education on the growth of very diverse economies. We have adhered to suggestions made by de la Fuente and Domenech (2001) and Vandebussche, Aghion and Meghir (2006), who stress the importance of using robust human capital proxies. This is particularly crucial for panel data estimations for which poor quality data have tended to drive previous empirical results. Thus, on the one hand, we have relied on Cohen and Soto's (2006) human capital database, which has been shown to out-perform other databases and to provide more consistent estimates of education levels both across countries and over time. On the other hand, however, a further influential strand of literature (see Hanushek and Kimko (2000) and Hanushek and Woessmann (2009)) argues that the quality of education systems, rather than the "quantity" of formally completed education, represents a better approximation of human capital.

Our empirical results are strikingly robust to the use of both quantity<sup>54</sup> and/or quality-human capital proxies. The impact of a marginal increase in either of the two proxies leads to faster convergence overall. However, and in contrast to the results recorded by Vandebussche, Aghion and Meghir (2006) and others, this effect is shown to be much larger for those economies which are farthest away from the technology frontier and endowed with smaller initial stocks of (or lower quality) tertiary education. In order to demonstrate the robustness of our results we built, in addition, a composite human capital indicator by jointly exploiting the quantitative and qualitative information on cross-country human capital. Our results are, once again, in line with our initial assumption.

Interestingly, adjusting the human capital indicators by the quality of education reduces the gap in the estimated returns of tertiary education between developed and developing countries. We argue that this result might be related to the lower signaling power of quantitative measures of human capital (such as, for instance, the average number of years of schooling) for developed countries.

This, in turn, could be attributed to the observed decrease in school and college selectivity over time, which would hinder the ability to capture the true level of the human capital of the developed countries' workforce.

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<sup>54</sup> Cohen and Soto's data provide details of the relative stock (quantity) of education in each country/year approximated by both the average number of years of schooling in primary, secondary and tertiary education as well as by the fraction of the workforce in each education category.



We provide empirical evidence supporting the hypothesis according to which "quantitative" measures of human capital, such as the average number of years of schooling, tend to underestimate the impact of tertiary education on the economic growth of countries at higher stages of development. Our main results can be reconciled with the microeconomic evidence pointing to decreasing returns to investment in tertiary education at higher stages of development, as has been reported by Psacharopoulos (1994) and Psacharopoulos and Patrinos (2002) among others. A more formal analysis of this hypothesis, however, is left for future research.

Evidence of the heterogeneous impact of tertiary education at different stages of development is also robust to a wide array of controls and, especially, to the introduction of differences in institutional quality indicators across countries.

Institutions, as expected, are generally shown to increase the speed of economic convergence, in line with previous empirical studies, including Hall and Jones (1999) and Acemoglu et al. (2001). In our study we control for differences in legal origin and in religious fractionalization across countries, in line with the empirical evidence provided by la Porta et al. (2008) and Alesina et al. (2003), as well as for differences in legal systems, openness to trade and other institutional sub-indicators included in the EFW index.

Our results are also fully corrected for the likely presence of endogeneity by applying a wide array of estimators, such as Instrumental Variables (for both panel and cross section analyses) and two-step efficient GMM estimators. To conclude, and by means of supporting our empirical evidence, we have presented a simple, modified version of the technology "catch-up" model à la Barro and Sala-i-Martin (1997), which accommodates the assumption regarding the heterogeneity of human capital across countries at different stages of development. We have thus linked the cost of innovation and imitation to each country's human capital composition. Solving the model for both the leader and follower's growth rates and calibrating the parameters as in our raw descriptive statistics (endowing the leader with higher skills and better institutions than the follower), we find additional confirmation of the validity of our empirical results and of the greater marginal effect of tertiary education on growth at lower stages of development.

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## ANNEX

**TAB 1: Descriptive Statistics**

Variable	Obs	Mean	Std. Dev.	Min	Max
<b>ALL</b>					
TFP gap	412	0.34	0.27	0.00	1.00
Institutions	307	5.84	1.17	2.9	8.6
Mean Years Tertiary	440	0.23	0.27	0.00	1.40
Mean Years Secondary	440	0.72	0.78	0.00	3.36
Mean Years Primary	440	1.43	1.12	0.04	5.13
Tertiary Fraction	440	0.06	0.07	0.00	0.35
Secondary Fraction	440	0.12	0.13	0.00	0.56
Primary Fraction	440	0.24	0.19	0.01	0.85
<b>OECD</b>					
TFP gap	104	0.69	0.17	0.21	1.00
Institutions	84	6.9	0.75	5.3	8.6
Mean Years Tertiary	105	0.51	0.32	0.04	1.40
Mean Years Secondary	105	1.53	0.89	0.08	3.36
Mean Years Primary	105	2.32	1.33	0.18	5.13
Tertiary Fraction	105	0.13	0.08	0.01	0.35
Secondary Fraction	105	0.25	0.15	0.01	0.56
Primary Fraction	105	0.39	0.22	0.03	0.85
<b>DEVELOPING</b>					
TFP gap	297	0.22	0.17	0.00	0.90
Institutions	216	5.38	1.00	2.9	7.5
Mean Years Tertiary	323	0.14	0.17	0.00	1.30
Mean Years Secondary	323	0.46	0.54	0.00	2.89
Mean Years Primary	323	1.13	0.88	0.04	4.54
Tertiary Fraction	323	0.03	0.04	0.00	0.32
Secondary Fraction	323	0.08	0.09	0.00	0.48
Primary Fraction	323	0.19	0.15	0.01	0.76

**TAB. 2: TFP GROWTH EQUATION, FRACTIONS**

Dependent Variable:

TFP growth rate

	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING
TFP gap	-0.040	-0.268**	0.034	-0.045	-0.362*	0.020	-0.001	0.017	-0.011
	[0.026]	[0.133]	[0.039]	[0.029]	[0.188]	[0.039]	[0.042]	[0.124]	[0.050]
Tertiary Fraction	0.195	-0.802	0.871***						
	[0.145]	[0.524]	[0.289]						
TFP gap*Tertiary Fraction	-0.261	1.003	-2.827***						
	[0.198]	[0.642]	[0.884]						
Secondary Fraction				0.237***	-0.363	0.542***			
				[0.075]	[0.357]	[0.121]			
TFP gap*Secondary Fraction				-0.260**	0.525	-1.426***			
				[0.102]	[0.477]	[0.418]			
Primary Fraction							0.222***	0.460	0.135*
							[0.086]	[0.324]	[0.072]
TFP gap*Primary Fraction							-0.335**	-0.652	-0.272
							[0.151]	[0.437]	[0.197]
Institutional Quality	0.015**	0.013	0.009	0.015**	0.021	0.009	0.018*	0.012	0.008
	[0.007]	[0.022]	[0.009]	[0.007]	[0.020]	[0.008]	[0.009]	[0.018]	[0.008]
Constant	-0.072*	0.136	-0.053	-0.080**	0.119	-0.061	-0.118**	-0.075	-0.046
	[0.040]	[0.126]	[0.050]	[0.041]	[0.155]	[0.047]	[0.054]	[0.162]	[0.051]
Observations	198	62	131	198	62	131	198	62	131
Number of id	84	21	61	84	21	61	84	21	61
R2	0.106	0.341	0.138	0.149	0.290	0.234	0.164	0.401	0.130
Hausman X(3)	3.39								
P-value	0.334								

Note: Random effect IV estimations are performed. Instruments are the 2<sup>nd</sup> lag of the explanatory variables. Standard Errors in brackets. Time dummies are included in all specification but not reported. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**TAB. 3:**  
**TFP GROWTH EQUATION, FRACTIONS**

Dependent Variable:  
 TFP growth rate

	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING
Tertiary Fraction	0.248*	0.144	0.838***						
	[0.149]	[0.279]	[0.271]						
TFP gap*Tertiary Fraction	-0.378*	-0.173	-2.606***						
	[0.195]	[0.322]	[0.769]						
Secondary Fraction				0.280***	0.122	0.513***			
				[0.083]	[0.182]	[0.102]			
TFP gap*Secondary Fraction				-0.340***	-0.181	-1.282***			
				[0.109]	[0.200]	[0.292]			
Primary Fraction							0.240***	0.452**	0.174**
							[0.080]	[0.181]	[0.070]
TFP gap*Primary Fraction							-0.382***	-0.648***	-0.352**
							[0.132]	[0.236]	[0.150]
Institutional Quality	0.008	-0.011	0.012	0.007	-0.004	0.010	0.020**	0.013	0.005
	[0.006]	[0.021]	[0.010]	[0.007]	[0.018]	[0.008]	[0.008]	[0.018]	[0.012]
Constant	-0.038	0.109	-0.069	-0.042	0.062	-0.066	-0.135**	-0.073	-0.038
	[0.036]	[0.147]	[0.060]	[0.042]	[0.129]	[0.046]	[0.057]	[0.148]	[0.073]
Observations	198	62	131	198	62	131	198	62	131
Number of id	84	21	61	84	21	61	84	21	61
R-Sq	0.0773	0.0700	0.152	0.124	0.0915	0.243	0.159	0.390	0.113

Note: Random effect IV estimations are performed. Instruments are the 2<sup>nd</sup> lag of the explanatory variables. Standard Errors in brackets. Time dummies are included in all specification but not reported. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**TAB. 4:**  
**TFP GROWTH EQUATION, AVERAGE YEARS OF**  
**SCHOOLING**

Dependent Variable:

TFP growth rate

	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING
TFP gap	-0.067 [0.041]	0.456* [0.261]	-0.035 [0.049]	-0.085 [0.054]	0.335 [0.278]	-0.093 [0.067]
Tertiary Schooling	0.004 [0.004]	-0.066*** [0.022]	0.008** [0.004]	0.001 [0.005]	-0.071** [0.028]	0.010* [0.005]
Primary+Secondary Schooling	0.003 [0.007]	0.419** [0.167]	-0.003 [0.008]	0.013 [0.010]	0.357** [0.153]	-0.003 [0.012]
TFP gap* Tertiary Sch.	0.003 [0.026]	0.135** [0.059]	-0.208** [0.098]	0.009 [0.032]	0.130** [0.065]	-0.238** [0.120]
TFP gap* Prim.+Sec. Sch.	0.005 [0.005]	-0.086** [0.037]	0.005 [0.010]	-0.001 [0.006]	-0.074** [0.036]	0.013 [0.014]
Institutional Quality				0.018* [0.010]	0.017 [0.024]	0.006 [0.012]
Constant	0.035* [0.018]	-0.778** [0.330]	0.050*** [0.019]	-0.087 [0.064]	-0.763** [0.335]	0.025 [0.082]
Observations	226	62	158	196	62	129
Number of id	86	21	63	84	21	61
R-Sq	0.0626	0.486	0.0936	0.123	0.455	0.150

Note: Random effect IV estimations are performed. Instruments are the 2<sup>nd</sup> lag of the explanatory variables. Standard Errors in brackets. Time dummies are included in all specification but not reported. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**TAB. 5:**  
**TFP GROWTH EQUATION, AVERAGE**  
**YEARS OF SCHOOLING**

Dependent Variable: TFP growth rate						
	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING
Tertiary Schooling	0.002 [0.003]	-0.053** [0.022]	0.007* [0.004]	-0.001 [0.004]	-0.072*** [0.028]	0.008 [0.006]
Primary+Secondary Schooling	0.007 [0.007]	0.199** [0.085]	-0.001 [0.007]	0.011 [0.008]	0.230** [0.092]	0.002 [0.012]
TFP gap* Tertiary Sch.	0.001 [0.028]	0.145** [0.063]	-0.222** [0.097]	-0.017 [0.027]	0.151** [0.064]	-0.247* [0.143]
TFP gap* Prim.+Sec. Sch.	-0.002 [0.003]	-0.032*** [0.012]	0.000 [0.007]	-0.004 [0.004]	-0.035*** [0.012]	0.002 [0.011]
Institutional Quality				0.011 [0.007]	0.026 [0.022]	-0.000 [0.016]
Constant	0.016 [0.015]	-0.295** [0.143]	0.042*** [0.016]	-0.061 [0.049]	-0.555** [0.277]	0.040 [0.107]
Observations	226	62	158	196	62	129
Number of id	86	21	63	84	21	61
R-Sq	0.0466	0.441	0.0870	0.0947	0.427	0.0960

Note: Random effect IV estimations are performed. Instruments are the 2<sup>nd</sup> lag of the explanatory variables. Standard Errors in brackets. Time dummies are included in all specification but not reported. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.



**TAB. 6: TFP GROWTH EQUATION, FRACTIONS**

Dependent Variable:  
TFP growth rate

	(SYSGMM)			(SYSGMM)			(SYSGMM)		
	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING
TFP gap	-0.058*** [0.008]	-0.269*** [0.074]	-0.029*** [0.010]	-0.063*** [0.008]	-0.237** [0.094]	-0.037*** [0.012]	0.008 [0.012]	-0.007 [0.035]	-0.066*** [0.020]
Tertiary Fraction	0.008 [0.067]	-0.958** [0.399]	0.306*** [0.100]						
TFP gap*Tertiary Fraction	0.036 [0.091]	1.170** [0.525]	-1.033*** [0.200]						
Institutional Quality	0.015*** [0.002]	0.017* [0.010]	0.009*** [0.003]	0.008*** [0.002]	-0.000 [0.006]	0.005** [0.002]	0.015*** [0.002]	-0.006 [0.006]	0.010*** [0.002]
Secondary Fraction				0.218*** [0.042]	-0.406 [0.242]	0.348*** [0.056]			
TFP gap*Secondary Fraction				-0.156*** [0.057]	0.583* [0.307]	-0.743*** [0.121]			
Primary Fraction							0.142*** [0.023]	0.190*** [0.051]	0.128*** [0.024]
TFP gap*Primary Fraction							-0.234*** [0.029]	-0.268*** [0.065]	-0.150** [0.060]
Constant	-0.063*** [0.014]	0.110 [0.106]	-0.043** [0.017]	-0.033** [0.014]	0.198* [0.100]	-0.030** [0.013]	-0.092*** [0.011]	0.085 [0.057]	-0.055*** [0.016]
Observations	286	83	196	317	83	226	317	83	226
Number of id	87	21	64	87	21	64	87	21	64
Hansen P-value	0.0211	0.570	0.349	0.0587	0.403	0.242	0.00566	0.888	0.189
Hansen Stat	55.24	13.42	37.64	40.58	12.54	31.73	50.52	18.49	33.24
Instr. count	44	23	43	35	19	34	35	34	34
AR (2)- Pvalue	0.241	0.354	0.197	0.255	0.497	0.248	0.448	0.405	0.334
AR (2)- Stat	1.173	-0.927	1.290	1.139	-0.679	1.155	0.758	-0.833	0.966

Note: Two-step efficient Dynamic Panel System GMM estimations are performed by correcting for small sample biases. Standard Errors in brackets. Time dummies are included in all specification but not reported. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1. IV controls.....

**TAB. 7: TFP GROWTH EQUATION, FRACTIONS**

Dependent Variable:

TFP growth rate

	(SYSGMM)			(SYSGMM)			(SYSGMM)		
	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING	ALL	OECD	DEVELOPING
Tertiary Fraction	0.116 [0.214]	0.195 [0.122]	0.479 [0.334]						
TFP gap*Tertiary Fraction	-0.303 [0.283]	-0.372* [0.199]	-1.577** [0.735]						
Institutional Quality	0.011** [0.005]	0.004 [0.016]	0.008 [0.006]	0.005 [0.006]	0.001 [0.009]	0.005 [0.006]	0.015*** [0.003]	-0.006 [0.012]	0.010** [0.005]
Secondary Fraction				0.275*** [0.098]	0.061 [0.063]	0.419*** [0.137]			
TFP gap*Secondary Fraction				-0.351*** [0.121]	-0.136* [0.074]	-1.037*** [0.237]			
Primary Fraction							0.136* [0.074]	0.198** [0.074]	0.163* [0.082]
TFP gap*Primary Fraction							-0.220*** [0.083]	-0.278** [0.099]	-0.305*** [0.097]
Constant	-0.051* [0.030]	0.013 [0.106]	-0.045 [0.037]	-0.031 [0.035]	0.038 [0.062]	-0.035 [0.033]	-0.095*** [0.024]	0.078 [0.094]	-0.071** [0.027]
Observations	286	83	196	286	83	196	286	83	196
Number of id	87	21	64	87	21	64	87	21	64
Hansen P-value	0.0121	0.403	0.108	0.0117	0.674	0.274	0.0384	1.000	0.200
Hansen Stat	59.04	16.73	23.20	59.18	12.99	40.61	53.55	13.40	42.87
Instr. count	44	23	23	44	23	43	44	43	43
AR (2)- Pvalue	0.0723	0.244	0.205	0.124	0.181	0.116	0.923	0.515	0.311
AR (2)- Stat	1.797	1.164	1.266	1.537	1.337	1.573	-0.0970	-0.651	1.013

Note: Two-step efficient Dynamic Panel System GMM estimations are performed by correcting for small sample biases. Standard Errors in brackets. Time dummies are included in all specification but not reported. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**TAB. 8:**  
**TFP GROWTH EQUATION, AVERAGE**  
**YEARS OF SCHOOLING**

Dependent Variable: TFP growth rate			
(SYSGMM)			
	ALL	OECD	DEVELOPING
TFP gap	-0.088 [0.060]	0.316 [0.297]	-0.205** [0.085]
Tertiary Schooling	0.006 [0.006]	-0.055** [0.021]	0.015* [0.008]
Primary+Secondary Schooling	0.012 [0.013]	0.119 [0.081]	0.015 [0.016]
TFP gap* Tertiary Schooling	-0.001 [0.012]	0.052 [0.052]	-0.039** [0.016]
TFP gap* Prim.+Sec. Sch.	-0.006 [0.028]	-0.171 [0.130]	-0.015 [0.039]
Institutional Quality	0.013** [0.005]	0.019 [0.025]	0.008 [0.006]
Constant	-0.040 [0.050]	-0.346 [0.235]	0.014 [0.060]
Observations	284	83	194
Number of id	87	21	64
Hansen P-value	0.189	0.946	0.374
Hansen Stat	60.77	11.76	53.62
Instr. count	62	31	61
AR (2)- Pvalue	0.673	0.580	0.226
AR (2)- Stat	0.422	-0.553	1.210

Note: Two-step efficient Dynamic Panel System GMM estimations are performed by correcting for small sample biases. Standard Errors in brackets. Time dummies are included in all specification but not reported.  
 \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**TAB. 9:**  
**TFP GROWTH EQUATION, AVERAGE**  
**YEARS OF SCHOOLING**

Dependent Variable: TFP growth rate						
	(SYSGMM)			(SYSGMM)		
	ALL	OECD	DEV	ALL	OECD	DEV
TFP gap	-0.083** [0.033]	0.002 [0.034]	-0.199*** [0.065]	-0.079** [0.031]	-0.063 [0.045]	-0.150*** [0.036]
Tertiary Schooling	0.008 [0.005]	-0.063** [0.023]	0.015* [0.009]			
TFP gap* Tertiary Schooling	-0.005 [0.010]	0.076** [0.028]	-0.041** [0.017]			
Secondary Schooling				0.009 [0.007]	-0.043* [0.023]	0.020 [0.012]
TFP gap*Secondary Schooling				0.011 [0.015]	0.069*** [0.024]	-0.036 [0.023]
Institutional Quality	0.009* [0.005]	0.007 [0.012]	0.002 [0.005]	0.008 [0.006]	-0.009 [0.013]	0.005 [0.009]
Constant	0.000 [0.037]	-0.029 [0.087]	0.059 [0.053]	-0.002 [0.040]	0.143 [0.106]	0.023 [0.062]
Observations	284	83	194	282	83	192
Number of id	87	21	64	87	21	64
Hansen P-value	0.0810	0.917	0.395	0.0168	0.875	0.135
Hansen Stat	48.41	8.160	36.60	56.28	9.056	44.30
Instr. count	44	23	43	44	23	43
AR (2)- Pvalue	0.296	0.703	0.142	0.551	0.918	0.198
AR (2)- Stat	1.045	-0.381	1.468	0.597	0.103	1.289
			IV	IV	IV	IV
	IV controls	IV controls	controls	controls	controls	controls

Note: Two-step efficient Dynamic Panel System GMM estimations are performed by correcting for small sample biases. Standard Errors in brackets. Time dummies are included in all specification but not reported.

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**TAB: 10**  
**TFP GROWTH EQUATION**  
**EDUCATION QUALITY**

	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	OECD	DEVL.	ALL	OECD	DEVL.
	OLS	OLS	OLS	GMM	GMM	GMM
Cognitive Skills index	0.018*** [0.004]	-0.032 [0.038]	0.013* [0.006]	0.018** [0.007]	-0.016 [0.026]	0.015** [0.006]
Cogn* TFPgap	-0.012*** [0.002]	-0.012** [0.004]	-0.018*** [0.004]	-0.015*** [0.005]	-0.011*** [0.002]	-0.022*** [0.005]
Institutional Quality	0.003 [0.005]	0.006 [0.007]	0.003 [0.008]	0.012 [0.010]	0.003 [0.006]	0.012** [0.005]
Constant	-0.052** [0.024]	0.189 [0.159]	-0.024 [0.044]			
Observations	43	20	21	43	20	21
R-squared	0.396	0.551	0.515	0.312	0.319	0.381
Hansen J-stat				7.133	6.352	6.44
Pvalue				0.3087	0.3849	0.2657
Kleibergen-Paap rk Wald F statistic				4.791	2.995	15.816
Stock-Yogo's Critical Value						
*20, **10, ***5% maximal relative bias				4.73	4.73	9.92**

Robust standard errors in brackets, \*\*\* p<0.01, \*\* p<0.05, \* p<0.1. Institutions and Human capital variables are taken as endogenous and instrumented by country specific legal origin, religion fractionalization and average education expenditures over the period (for OECD) and lagged human capital as detailed in the text. Continent dummies are added in all specification but not reported.

**TAB: 11**  
**TFP GROWTH EQUATION**  
**EDUCATION QUALITY**

	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	OECD	DEVL.	ALL	OECD	DEVL.
	OLS	OLS	OLS	GMM	GMM	GMM
Cognitive Tertiary (Fraction)	0.016	0.024	0.048	0.021	0.016	0.054
	[0.026]	[0.020]	[0.061]	[0.021]	[0.013]	[0.043]
Cognitive Tertiary fraction *TfpGap	-0.051*	-0.040*	-0.184**	-0.084***	-0.053***	-0.180***
	[0.028]	[0.022]	[0.078]	[0.028]	[0.013]	[0.059]
Institutional Quality	0.006	-0.010	0.002	0.009	-0.005*	0.001
	[0.004]	[0.009]	[0.007]	[0.008]	[0.003]	[0.008]
Constant	-0.004	0.101	0.018			
	[0.028]	[0.064]	[0.046]			
Observations	43	20	21	43	20	21
R-squared	0.152	0.375	0.301	0.197	0.337	0.206
Hansen J-stat				4.175	11.104	5.054
Pvalue				0.6531	0.0852	0.4094
Kleibergen-Paap rk Wald F statistic				4.278	23.725	15.83
Stock-Yogo's Critical Value						
*20, **10, ***5% maximal relative bias				4.73	17.7***	9.92**

Robust standard errors in brackets \*\*\* p<0.01, \*\* p<0.05, \* p<0.1. Cognitive Tertiary (fraction) is the "Cognitive index adjusted measure" of Tertiary fraction of workforce. Institutions and Human capital variables are taken as endogenous and instrumented by country specific legal origin, religion fractionalization and average education expenditures over the period (for OECD) and lagged human capital as detailed in the text. Continent dummies are added in all specification but not reported.

**TAB: 12**  
**TFP GROWTH EQUATION**  
**EDUCATION QUALITY**

	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	OECD	DEVL.	ALL	OECD	DEVL.
	OLS	OLS	OLS	GMM	GMM	GMM
Cognitive Tertiary (Years schooling)	0.004 [0.007]	0.006 [0.005]	0.012 [0.015]	0.005 [0.005]	0.004 [0.003]	0.014 [0.011]
Cognitive Tertiary (Years)* TFP Gap	-0.013* [0.007]	-0.010* [0.006]	-0.046** [0.020]	-0.021*** [0.007]	-0.013*** [0.003]	-0.045*** [0.015]
Institutional Quality	0.006 [0.004]	-0.010 [0.009]	0.002 [0.007]	0.009 [0.008]	-0.005* [0.003]	0.001 [0.008]
Constant	-0.004 [0.028]	0.101 [0.064]	0.018 [0.046]			
Observations	43	20	21	43	20	21
R-squared	0.152	0.375	0.301	0.197	0.337	0.206
Hansen J-stat				4.175	11.104	5.054
Pvalue				0.6531	0.0852	0.4094
Kleibergen-Paap rk Wald F statistic				4.278	23.725	15.83
Stock-Yogo's Critical Value						
*20, **10, ***5% maximal relative bias				4.73	17.7***	9.92**

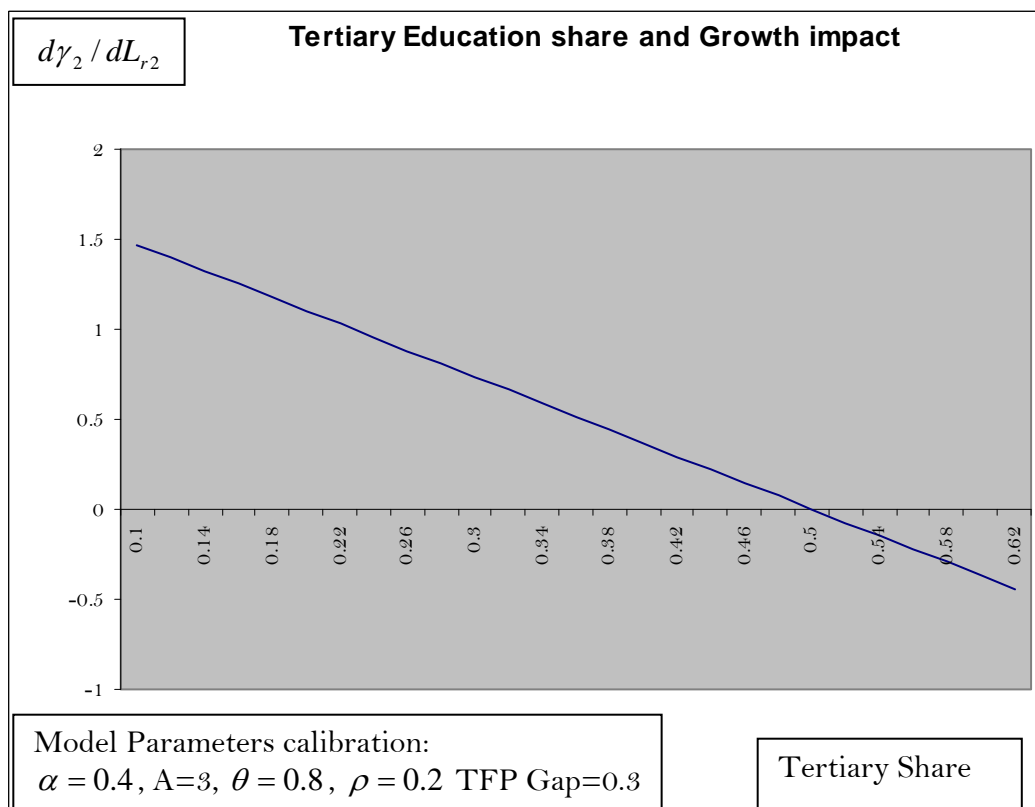
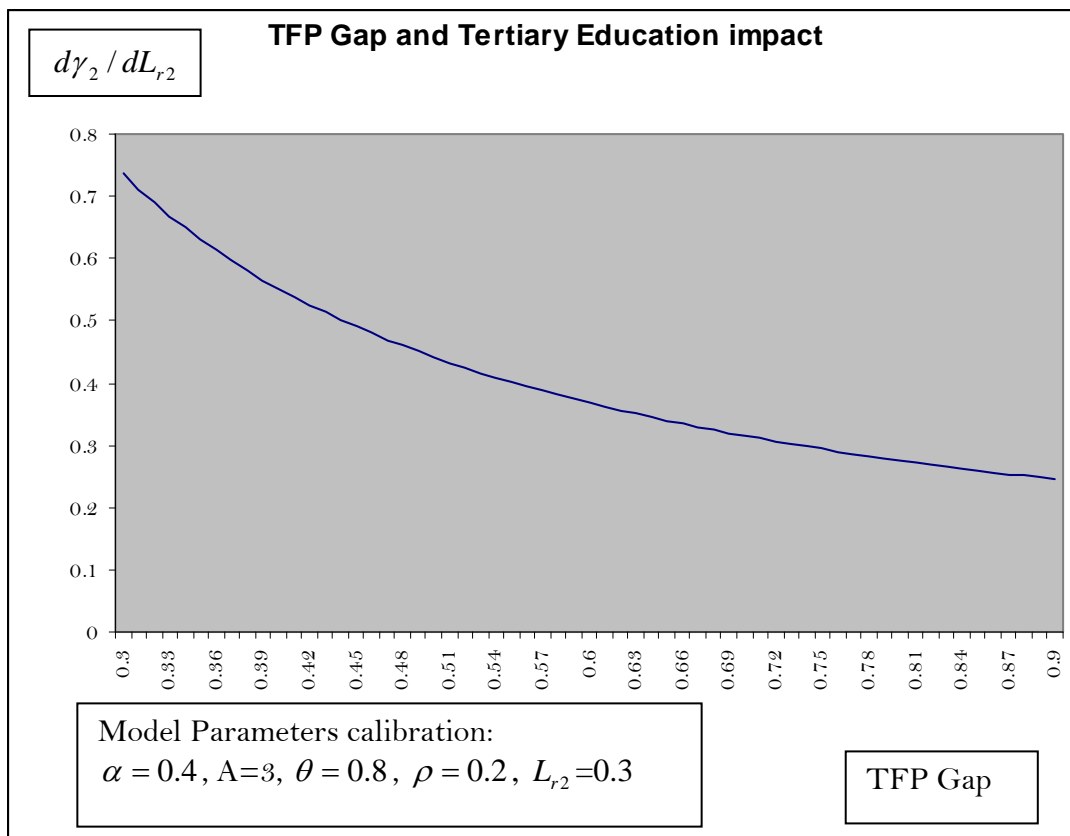
Robust standard errors in brackets.\*\*\* p<0.01, \*\* p<0.05, \* p<0.1. Cognitive Tertiary (Years schooling) is the "Cognitive index adjusted measure" of Tertiary years of schooling. Institutions and Human capital variables are taken as endogenous and instrumented by country specific legal origin, religion fractionalization and average education expenditures over the period (for OECD) and lagged human capital as detailed in the text. Continent dummies are added in all specification but not reported.

**Appendix 1**  
**OLS: Cognitive skills**  
**regression**

VARIABLES	(1) cognitive	(2) cognitive	(3) cognitive
Average years of Tertiary education in 1960	0.408 [0.621]	-0.707 [0.505]	4.184** [1.669]
Institutional quality	0.292*** [0.081]	0.207** [0.078]	0.295* [0.173]
Constant	2.717*** [0.514]	3.347*** [0.478]	2.630** [1.007]
Observations	50	21	27
R-squared	0.759	0.678	0.655
r2	0.759	0.678	0.655
F	14.01	6.311	5.161

Robust standard errors in brackets \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.  
 Continental dummies are included but not reported.





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