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INNOVATION, PRODUCTIVITY AND ECONOMIC DEVELOPMENT IN LATIN AMERICA AND THE CARIBBEAN

by

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PREFACE

Just prior to the current global financial crisis,Latin America enjoyed several banner years of economic growth. Even so, the region's long-term growth performance, when compared to that of other developing regions or to OECD countries, remains too low to trigger a substaintial shift towards higher levels of development. Whatis holding the region back? In macroeconomic terms, there are two possible explanations. First, it could be that Latin American economies are experiencing slow growth of population and slow rates of investment – these are the factors of production that allow output to grow. Alternatively, it could be that economies in the region do a comparatively poor job of combining those factors of production. Which is it: slow factor accumulation or low productivity?

This working paper by Christian Daude of the OECD Development Centre identifies low productivity as the culprit preventing Latin American economies from converging to standards of living observed in other emerging economies and in the OECD. Thus, this paper's conclusion reminds us of the fundamental importance of understanding better the barriers to innovation and technology adoption on the one hand, and the identification of policies that increase economic efficiency and spur economic growth, on the other. These are the twin goals of the Innovalatino initiative, a joint venture between the OECD Development Centre and the INSEAD Business School. The first report of the Innovalatino project is set to be presented at the European Union/Latin American and Caribbean Summit in Spain in May 2010. Daude's paper is a background study for that report..

In this paper, Daude explores why productivity grows more slowly in Laitn America than elsewhere. He argues that economic and political institutions, as well as differences in human capital and access to finance, explain the region's gap with respect to OECD countries regarding the diffusion of new technologies. In an interesting extension, the paper looks beyond productivity growth to consider the determinants of life expectancy; arguably, this is a more immediately relevant measure of well-being than productivity or GDP per capita, and one in which the diffusion of new technologies and practices is also crucial. Daude shows that Latin American countries have been much more successful in promoting longer lives than in raising productivity. Even controlling for initial levels of life expectancy, the level of development, the availability of human resources in the health sector, and the decline in infant mortality – all linked to rather "low-tech" innovations – on average, the region shows a higher speed of convergence to the frontier than the rest of the world. This raises the curious question of why technological change in the health sector seems to spread more easily than knowledge in other parts of the economy. Although more detailed research is needed, Daude suggests that the comparatively better performance in improving health may owe to fewer political and economic barriers to knowledge diffusion at the national and international levels in this sector than in other sectors of the economy.

Our hope is that the results of the Innovalatino project, and of this working paper in particular, will promote fruitful policy dialogue that will ultimately lead to an inflexion in Latin America's productivity growth, with benefits at all levels of the social pyramid.

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RÉSUMÉ

En Amérique latine, le PIB par habitant n'a eu de cesse depuis plusieurs décennies de reculer par rapport à celui des pays à hauts revenus et d'autres pays de références. Les mauvaises performances de la région en terme de croissance sont l'une des principales raisons pour lesquelles la réduction de la pauvreté, et de façon générale le niveau de vie, sont bien plus faibles que ceux observés dans les pays. Dans cet article, nous explorons certaines des raisons potentielles de cette mauvaise performance à l'aide de techniques comptables de développement. Les résultats tendent à montrer que la principale cause de l'absence de convergence de la région est la productivité totale des facteurs. Afin de rechercher pourquoi ces pays n'ont pas comblé leur retard de productivité, nous analysons les déterminants des technologies de diffusion, et en particulier internet et les technologies de téléphonie mobile. Les résultats empiriques montrent que les institutions, la capacité d'absorption (capital humain) et les contraintes financières sont les principales variables explicatives de l'écart qui existe entre les pays de l'OCDE et ceux de l'Amérique latine concernant la diffusion de ces technologies. Nous explorons également la performance de la région en matière de santé, mesurée par l'évolution de l'espérance de vie, et le rôle spécifique joué par l'innovation et l'adoption technologique. Finalement, un exercice de calibrage d'un modèle de croissance endogène nous permet d'évaluer jusqu'à quel point la différence de revenu par tête au sein de la région est due à des problèmes d'allocation des facteurs ou à des distorsions qui diminuent les incitations à innover. Les résultats varient fortement d'un pays à l'autre au sein de la région. Si pour certains pays nous mettons en évidence un « manque d'innovation », pour d'autres, la faible accumulation de facteurs demeure le principal problème.

Classification JEL: O10; O30; O47
Mots clé: productivité totale des facteurs; innovation; croissance économique ; Amérique Latine

ABSTRACT

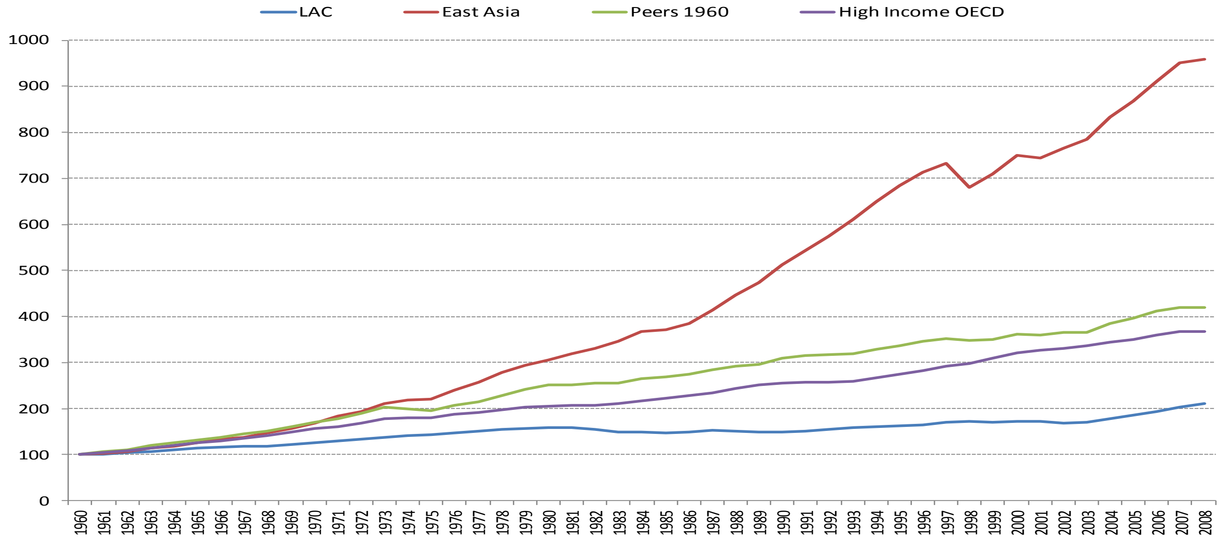
GDP per capita in Latin America has been falling behind high-income countries and other benchmarks for decades and the region's mediocre growth performance is one of the main reasons why poverty reduction, and living standards more generally, in the region is well below that observed in peer countries. In this paper, we explore some of the potential roots of this poor performance by using development accounting techniques. The results point towards total factor productivity as the main culprit for the region's lack of convergence. In order to investigate what causes the lack of productivity catch-up, we analyse the determinants of technology diffusion, in particular of internet and mobile phone technologies. The empirical results show that institutions, absorption capacity (human capital), and financial constraints are the main explanatory variables of the diffusion gaps in these technologies between the OECD and Latin America. We also explore the performance of the region in terms of health outcomes, reflected in the evolution of life expectancy, and the specific role played by technological innovation and adoption. Finally, a calibration exercise of an endogenous growth model allows us to assess the extent to which the region's per capita income gap is due to problems in factor accumulation or distortions that reduce the incentives to innovate; the results point to very different situations across countries in the region. While for some countries we find evidence of "innovation shortfalls", other countries' problems concentrate around low factor accumulation.

JEL Classification: O10; O30; O47
Keywords: Total factor productivity; innovation; economic growth; Latin America

I. INTRODUCTION

Economic growth in Latin America and the Caribbean (LAC) has been low and volatile for several decades. As shown in Figure 1 and 2, between 1960 and 2008, GDP per capita in the average country in the region multiplied by a factor of just 2.1, which implies an average annual growth rate of GDP per capita of around 1.5 per cent (in PPP terms). This contrasts sharply with the growth experience of East Asian countries. While in 1960 LAC was on average 60 per cent richer than the average East Asian country, in 2008 GDP per capita in East Asia was almost 3 times that in the LAC region! While part of this incredible divergence is due to the strong performance of East Asia, when compared to High-Income OECD countries[1] or countries that had levels of GDP per capita very similar to those in the region in 1960,[2] the main facts still hold: on average, there is a steady decline in Latin America's GDP per capita relative to any of these groups.[3]

Figure 1. **Evolution of GDP per capita in PPP terms across regions (index 1960 = 100)**



Source: Own calculations based on Penn World Tables version 6.2 and World Development Indicators.

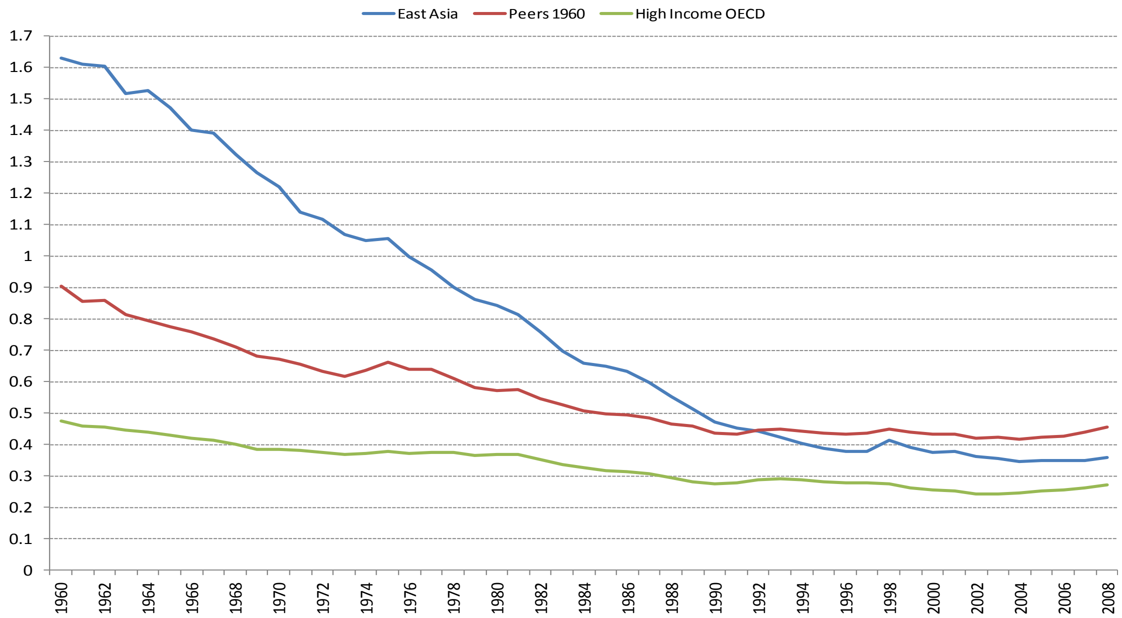
1 This group includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, United Kingdom and United States.

2 This group includes Algeria, Fiji, Greece, Hong Kong, Hungary, Iran, Japan, Jordan, Portugal and Singapore.

3 In the paper we use simple geometric means for group averages to represent the "average country" in each region.

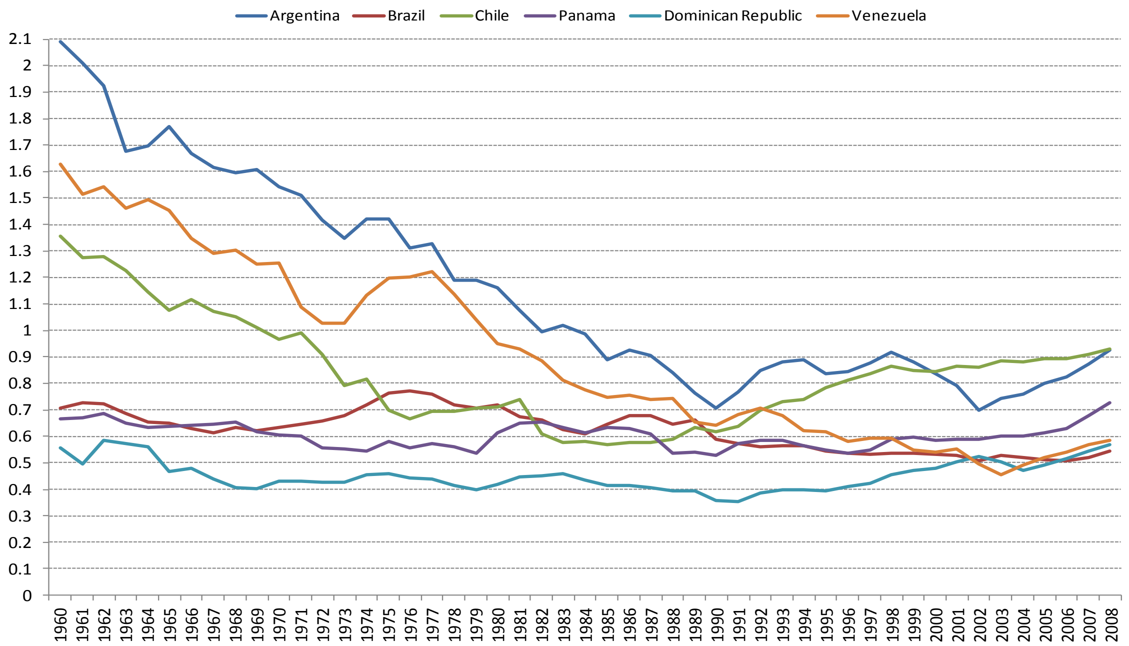
Furthermore, as Figure 3 shows, even countries that are regional success stories (e.g. Chile and Dominican Republic since the late 1980's and early 1990's, respectively) exhibit only a modest performance, recovering only part of the lost ground in the earlier decades, when compared to other experiences around the world.

Figure 2. **Ratio of LAC GDP per capita versus benchmarks**



Source: Own calculations based on Penn World Tables version 6.2 and World Development Indicators.

Figure 3. **Ratio of GDP per capita (PPP) versus peer countries**



Source: Own calculations based on Penn World Tables version 6.2 and World Development Indicators.

Despite the fact that the period 2003-2008 presented the highest per capita GDP growth rate in LAC in the last 50 years, the figures above show that this positive news has so far had a modest impact on closing the development gap with respect to other regions. Growth during this period in LAC has clearly been higher than in the peer countries (Figures 2 and 3), but compared to East Asia or even the High-Income OECD (Figure 2), the performance has been good, but far from being quantitatively important so far.

The present paper explores the some of the potential explanations behind this disappointing performance of the region. In section II, we show some development accounting exercises that point towards total factor productivity (TFP), the efficiency with which factors of production are combined in the economy, as the main reason for the region's lack of convergence in GDP per capita to the frontier. Section III explores some of the explanations behind the region's persistent TFP gap. Furthermore, we analyse the factors that explain the gap in the adoption and diffusion of new technologies in the region with respect to OECD countries. Of course, GDP per capita is not the only measure of economic progress; accordingly in section IV, we discuss the convergence of life expectancy in the region compared to the rest of the world. In particular, we relate the good performance in the region on this "extensive" margin to the discussion on TFP and convergence of the previous sections. Section V analyses the existence of innovation gaps in the region based on the calibration of an endogenous growth model. In section VI, we conclude and discuss some policy implications of our main results.

II. DEVELOPMENT ACCOUNTING[4]

What lies behind the disappointing performance of LAC discussed in the previous section? As we will show, according to standard development accounting exercises, mediocre TFP is the main culprit in most countries of the region.

Growth and development accounting techniques traditionally rely on a decomposition on output based on a aggregate production *f*(.) with constant returns to scale that maps accumulated production factors (physical and human capital, denoted by *K* and *H* respectively) into final output (*Y*). In particular, we assume a Cobb-Douglas technology that takes the following form:

$$Y = f(K,H) = AK^{\alpha}H^{1-\alpha} = AK^{\alpha}(hL)^{1-\alpha} . \qquad (1)$$

We follow the literature since Hall and Jones (1999) by assuming that the stock of human capital can be measured by the product of the quality of the labour force (*h*) and the labour force (L).[5] The parameter *A* is TFP, which represents the efficiency with which factors of production are combined in the economy.

As it is standard in the literature (see Klenow and Rodriguez-Clare, 2005), we assume that the capital share (α = 1/3) is the same across countries and constant over time. This is a standard assumption in the literature which is mainly based on the evidence for the United States. While Gollin (2002) shows that there is a significant variation across countries in this parameter, this variation does not follow any particular pattern. In particular, once entrepreneurship and informality are taken into account, it is not related to the level of development (GDP per capita).

Using series of physical and human capital,[6] we compute our measure of TFP by:

$$A = \frac{Y}{K^{\alpha}(hL)^{1-\alpha}} . \qquad (2)$$

Unfortunately, internationally comparable data on physical capital formation and human capital are available until 2005, such that the last growth spur cannot be analysed entirely here. However, as discussed in the previous section, GDP per capita relative to all benchmarks has not changed too much in the 2006 – 2008 period, such that the rather structural approach taken here – focusing on trend TFP – assures that the results remain valid.

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4 The analysis in this section draws heavily on previous work by Daude and Fernández-Arias (2010).

5 Of course, this assumes perfect substitutability between skilled and unskilled labour. See Caselli (2005) for the implications of using a lower elasticity of substitution between different levels of skills.

6 See the appendix for details regarding the data.

The evolution of TFP computed using equation (2) for the average LAC country is shown in Figure 4. As the figure shows, TFP in the average country of the region grew until the late 1970s and has declined since then, rebounding somewhat only in recent years.[7]

Figure 4. Evolution of TFP for the average LAC country (1960 = 1)

Source: Daude and Fernández-Arias (2010).

It is important to point out that the evolution highlights an important aspect of TFP: in the standard growth literature it is assumed to measure technological progress, absolute declines are difficult to interpret in this way. Thus, a more general interpretation of TFP is required. In particular, we think that the correct interpretation is that measured TFP reflects also the degree of efficiency with which markets and institutions work to combine and allocate productive factor in the economy. Clearly, under this broader interpretation, efficiency can decline in absolute terms for a prolonged period of time, as we observe for the case of LAC.

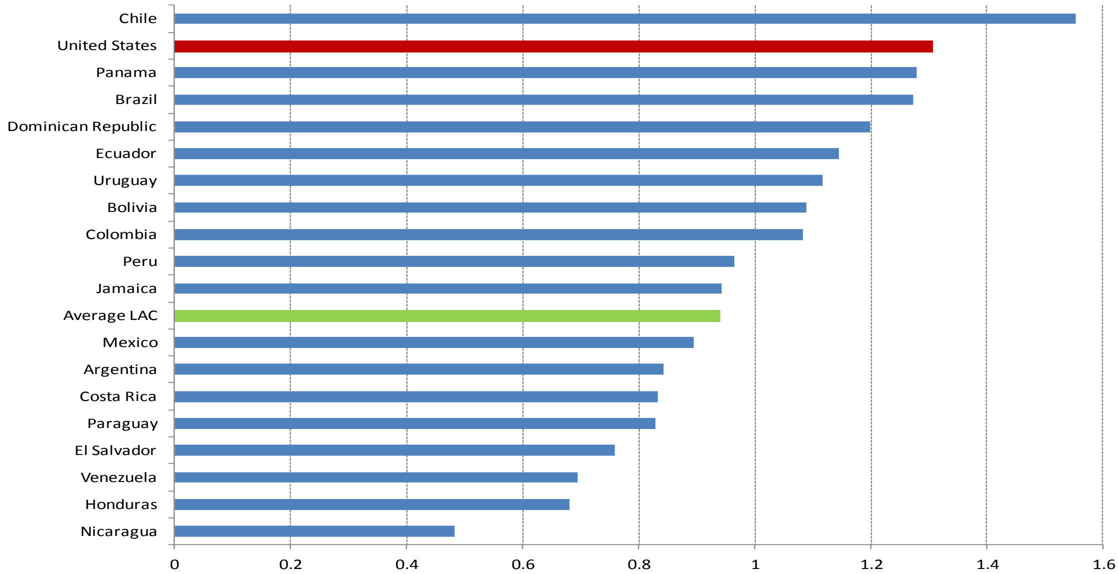
As Figure 5 shows, there is almost an even split between countries in the region that in 2005 exhibit higher levels of TFP than in 1960 (8 cases) and those who have lower levels of efficiency today than in the 1960s (10 cases). Furthermore, the regional leader in terms of TFP growth performance (Chile) increased it level of TFP be around 55 per cent, which is approximately equivalent to a 1 per cent growth rate per annum during the period, almost twice the rate of TFP growth for the United States.[8] While Chile is the only country in the region where TFP grew faster than in the United States, TFP growth in the US is close to the median in our sample, which implies that in more than 30 countries TFP growth was actually higher, such that

7 Part of this end-of-sample rebound is driven by the nature of the Hodrick-Prescott filter used to analyse these data. Therefore, this increase in the recent period should not be extrapolated, given that the estimates would probably be revised significantly once more data would become available.

8 Nevertheless, the United States continues to be the country with the highest TFP level in 2005.

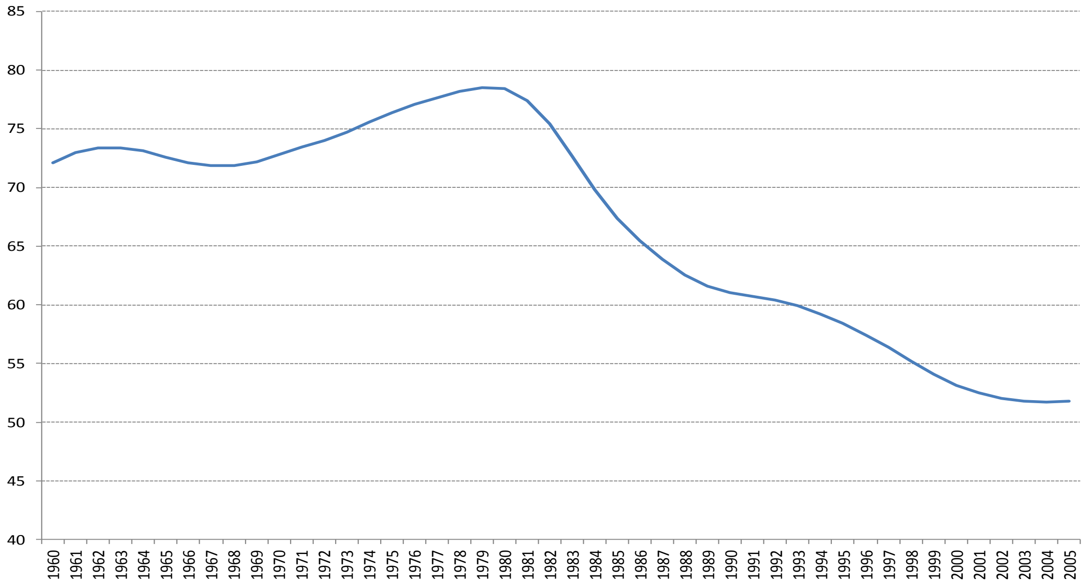
convergence to the frontier is not a rare event. This is in line with the importance of productivity convergence as a factor of convergence in GDP per capita emphasised by Bernard and Jones (1996).

Figure 5. **TFP ratios (2005 versus 1960)**



Source: Own calculations based on Daude and Fernández-Arias (2010).

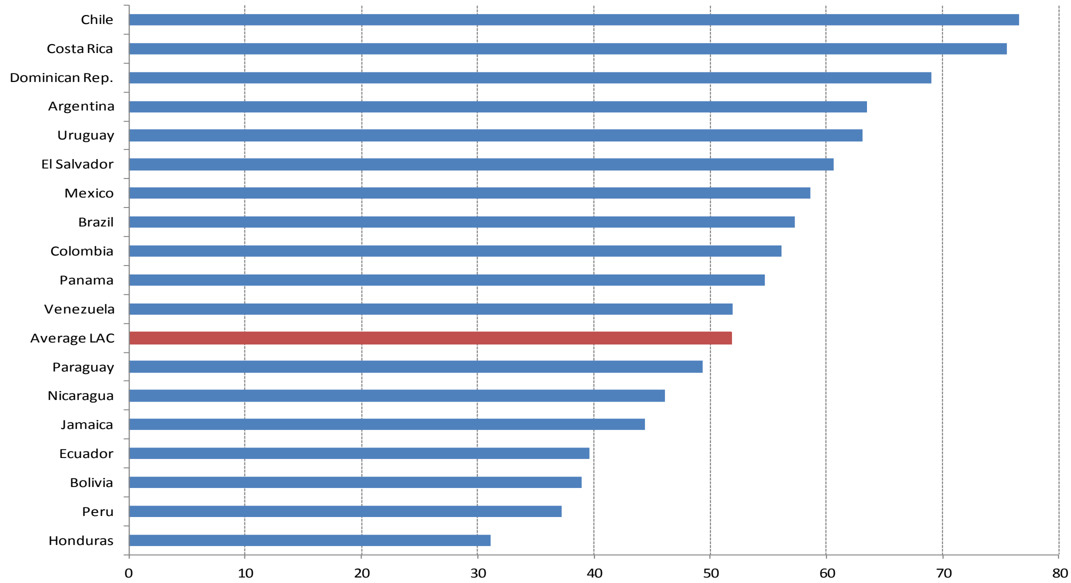
Figure 6. **Average LAC TFP relative to United States (per cent)**



Source: Daude and Fernández-Arias (2010).

In Figure 6 and 7, we show TFP levels for the average country in LAC over time and for each country as of 2005 with respect to the United States (which is usually considered the frontier), respectively. As it can be seen, TFP has been falling behind since the early 1980s from an efficiency of almost 80 per cent to only 52 per cent in 2005. Thus, a given amount of production factors produces only half the output in the typical LAC country than it would be feasible producing in the United States. There is however a relatively large dispersion across countries in the region in terms of TFP. For example, in Chile or Costa Rica TFP is around ¾ of US TFP, while at the other end of the spectrum in Honduras or Peru it is only around 30-40 per cent. These gaps are huge, given that they imply that Honduras would triple it income per capita, if it could close the efficiency gap with respect to the United States.[9]

Figure 7. **TFP relative to the United States in 2005 (per cent)**



Source: Daude and Fernández-Arias (2010).

In general, from a development perspective we are interested in decomposing and comparing GDP per capita (y). For this purpose equation (1) can be written in per capita terms:

$$y = \frac{Y}{N} = A\left(\frac{K}{L}\right)^{\alpha} h^{1-\alpha} \frac{L}{N} = Ak^{\alpha} h^{1-\alpha} f\ , \qquad (3)$$

where the last term (*f*) is the share of the labour force in the total population.[10]

Physical capital investment clearly depends on the level of TFP. To take this indirect effect of TFP into account, following Klenow and Rodriguez-Clare (1997) the production function (3) can be rewritten in "intensive" form as:

$$y = A^{\frac{1}{1-\alpha}} \kappa^{\frac{\alpha}{1-\alpha}} hf\ , \qquad (4)$$

9 It is important to notice that the dispersion in TFP gaps is smaller than GDP per capita gaps in the region (the coefficient of variation for TFP gaps is half that of GDP per capita gap).

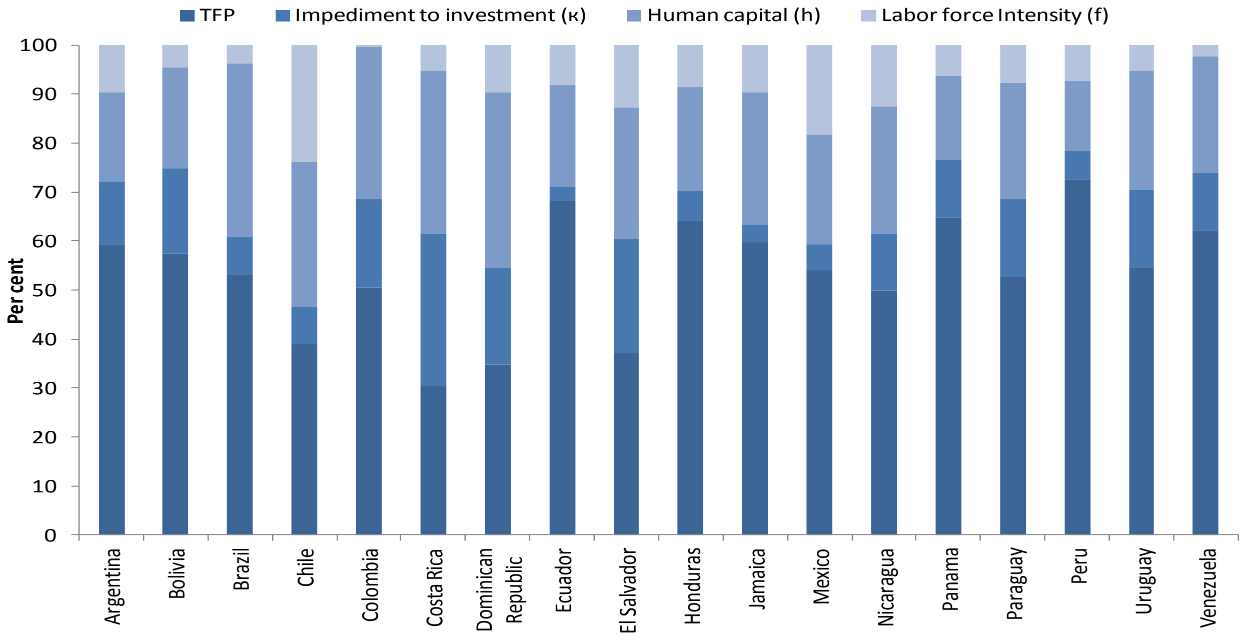
10 This ratio in turn results from the share of working age population (a demographic factor) and the rate of its participation in the labour force, an economic decision which for simplicity we consider exogenous.

where κ is the capital-output ratio (K/Y) which does not depend on TFP in the neoclassical growth model and does therefore reflect distortions specific to physical capital accumulation.[11] With respect to the frontier or any other benchmark (denoted by "*"), we have:

$$\frac{y}{y^*} = \left(\frac{A}{A^*}\right)^{\frac{1}{1-\alpha}} \left(\frac{\kappa}{\kappa^*}\right)^{\frac{\alpha}{1-\alpha}} \frac{h}{h^*} \frac{f}{f^*}, \qquad (5)$$

In Figure 8, we present the log-decomposition based on equation (5) by country with respect to the United States. As the graph shows, TFP explains most of the gap in income per capita with respect to the United States, but other factors are still important. On average, TFP account for 56 per cent of the gap, physical capital distortion for around 11, human capital for 24 per cent, and demographic and labour force participation factors for the remaining 8 per cent of the income per capita gap.

Figure 8. **Decomposition of GDP per capita gaps versus United States (2005)**



Source: Daude and Fernández-Arias (2010).

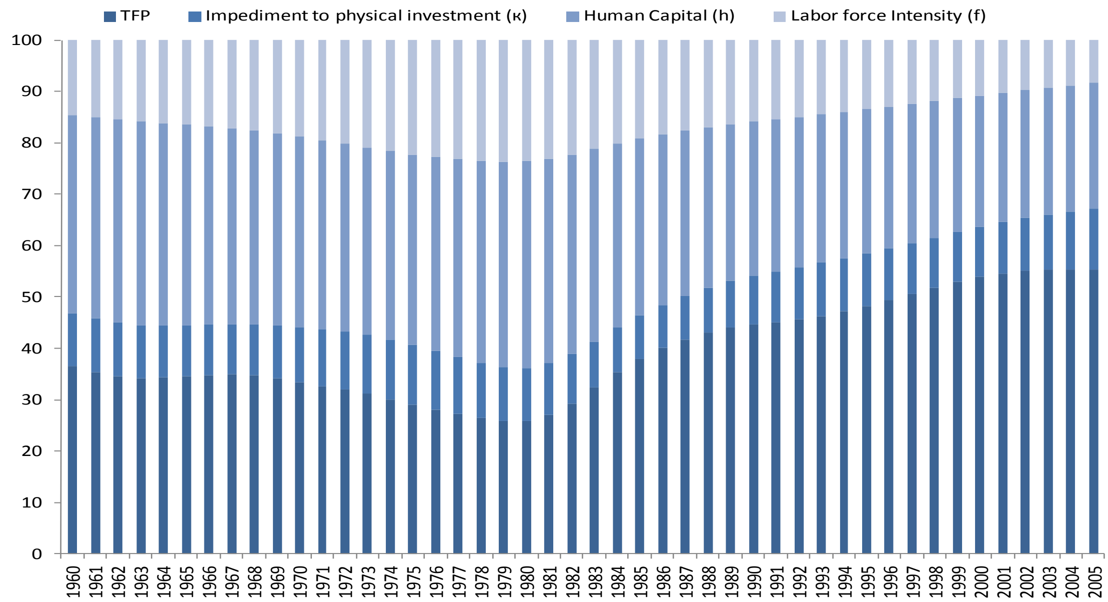
There are also interesting differences across countries in the region. On the one hand, in countries like Peru, Ecuador, Panama, Honduras and Venezuela, TFP is a major explanation of the income per capita gap, with a contribution between around 60 and 70 per cent. On the other hand, in economies like Costa Rica, Dominican Republic and El Salvador, the main explanation

11 This follows from simple profit maximisation in the neoclassical growth model. Observe that for now we assume human capital to be exogenous. Thus, human capital – just like TFP – has now two effects on output: a direct effect and an indirect effect through physical capital investment which is increasing in *h*.

come from factor distortions. Chile is also an interesting case. While TFP explains 39 per cent of the income per capita gap with respect to the United States, human capital explains nearly a third of it – a high contribution shared also with Brazil, Costa Rica and the Dominican Republic. Furthermore, labour market participation (rather than demographic) factors play an important role in explaining the income per capita gap in Chile (almost 24 per cent of the gap). This is driven by the fact that female labour participation is one of the lowest in the region (as of 2005 only 38.4 per cent of women of 15 years and older work in Chile, compared with a 52 per cent average in the region, and 52.6 per cent in high income countries, according to the *World Development Indicators* of the World Bank). While this could partially reflect preferences over leisure and work decisions as well as culture aspects, it seems reasonable to expect that a large part of this lower participation of women in the economy is caused by distortions whose elimination would be welfare improving.

Furthermore, as Figure 9 shows, over time the importance of TFP in explaining the average income gap of the region with respect to the United States has increased from around 37 per cent in 1960 to 55 per cent nowadays, with physical capital distortions accounting for a rather constant 10 per cent of the gap, and human capital reducing its importance from 39 per cent to 24 per cent.[12]

Figure 9. **Decomposition of GDP per capita gap (average LAC versus United States)**



Source: Daude and Fernández-Arias (2010).

Summing up, standard development accounting techniques show that TFP is the main reason why the region is not catching up. If countries in the region could eliminate the restrictions behind these low levels of TFP, welfare – measured by income per capita – would

12 Of course, as mentioned above, the potential gaps in the quality of education are captures by TFP rather than human capital (see Figure 10 below).

almost triple (increasing by a factor of 2.7) for the average LAC country. For example, operating at TFP levels similar to the United States would increase Honduras' income per capita (around USD 2 400 in PPP terms for 2005) to a similar level of Chile currently (almost USD 14 000 in PPP terms)! Even for a country such as Chile the gains are substantial: going from USD 13 300 per capita to almost USD 20 000.

Certainly, these significant figures raise immediately a series of questions. First, if gains from TFP improvements are so large, why have governments in the region not made the necessary changes and reforms to increase efficiency, as well as absorb and create more knowledge? Even if TFP captures broader institutional issues, many of the ideas and arrangements that seem to work in terms of productive efficiency could be relatively well-known and do not have to be invented from scratch, requiring therefore only limited investments of resources. Alternatively, the second group of questions refer to whether technological knowledge is really available at low or no cost of adoption? Third, related the previous question, is slow catch up with the frontier due to lack of absorption capacities or insufficient investment in ideas and R&D? We discuss some of these issues and supporting evidence in the next section.

III. WHAT IS BEHIND THE TFP GAP?

There are different ways to approach analytically the questions outlined above, which potentially lead to very different policy implications. Following the work by Parente and Prescott (1994 and 1999) and Prescott (1998), a possible interpretation is that knowledge is available to developing countries, but not fully incorporated because of vested interests that reduce competition and the economic incentive to operate at the frontier (see also Krussell and Rios-Rull, 1996). Thus, from this perspective what is needed is a clear understanding of the political and economic forces that hold back the institutional framework and market forces to adopt the best production practices. An application of this approach for the case of Latin America is Cole *et al.* (2005) who argue that trade protectionism, monopoly power and lack of competition are the main drivers of the persistently low levels of TFP in the region.

Related to this literature that emphasised aggregate inefficiencies, there is a literature that has focused on the interaction between distortions and the existence of heterogeneous firms, which lead to misallocations of factors (see Restuccia and Rogerson, 2008). This literature tends to focus on barriers to entry for new and more productive firms; barriers to exit that maintain inefficient firms in the market. For example, Hsieh and Klenow (forthcoming) find that TFP in manufacturing could be between 30 to 60 per cent higher in China and India, if factors were reallocated among firms to reproduce the US productivity distribution. A recent report by the Inter-American Development Bank shows that these types of misallocations are also significant in the manufacturing sector in Latin America (see Inter-American Development Bank, 2010).

A quite different emphasis comes from the literature labelled as "appropriate technologies".[13] This literature focuses on the issue that technological progress and innovation mainly take place in developed countries where factor endowments are different.[14] Furthermore, technological progress is often non-neutral with respect to factor endowments, [15] and there might be little substitutability between factors – either capital-labour or skilled-unskilled labour – as emphasised also by Caselli and Coleman (2006). Clearly, the conceptual debate regarding these issues is not yet settled in the literature. Caselli and Coleman (2006) and Jermanowksi (2007) show that relaxing the assumption of an aggregate Cobb-Douglas production function (making factors substitution harder), as well as allowing technical change to be biased towards the relative factor endowments of the developed world, reduce the contribution of TFP to income

13 The term was coined by an early contribution by Atkinson and Stiglitz (1969).

14 See Basu and Weil (1998) for capital-labour mismatches and Acemoglu and Zilibotti (2001) for skilled-unskilled labour.

15 Skill-biased technological progress plays and important role in Acemoglu and Zilibotti (2001).

gaps. However, the quantitative implications of these changes seem to be rather limited, such that TFP often continues to be the most relevant factor in explaining cross-country income dispersion. For the case of Latin America, Daude and Fernández-Arias (2010) present non-parametric estimations of the relative efficiency, using data envelope techniques, that give picture very similar to standard techniques in terms of the evolution over time and the size of the contribution of TFP to the development gap with respect to the frontier.

III.1. Correlation analysis between TFP and potential drivers

Next, we explore the relationship between TFP growth and levels with a series of variables that have been associated in the literature as potential drivers of productivity. In particular, the estimations in Table 1 focus on TFP growth during the latest decade for which data are available (1996-2005). In all regressions, we include the initial level of TFP to allow for convergence. Although the point estimates show a negative coefficient, consistent with the idea that countries further away from the frontier grew faster during this decade, it is not significant at conventional levels of confidence. Columns 1 to 7 introduce the explanatory variables one-by-one, in order to explore the simple correlation with TFP growth, while in column 8 we introduce all of them at once.

Table 1. **TFP growth and explanatory variables (1995-2005)**

Variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
Initial level of log TFP	-0.036	-0.006	-0.009	-0.038	-0.044	-0.016	-0.042	-0.073	-0.056
	(0.95)	(0.19)	(0.30)	(0.74)	(1.35)	(0.43)	(1.05)	(1.26)	(0.94)
Technological creation index	0.131							0.029	-0.085
	(2.37)*							(0.29)	(0.81)
Trade/GDP (%)		0.001						0.001	0.001
		(0.55)						(0.82)	(0.59)
FDI/GDP (%)			0.012					0.014	0.012
			(2.12)*					(1.00)	(0.88)
Private Sector Domestic Credit/GDP				0.001				0.001	0.001
				(1.66)				(0.61)	(0.42)
Regulatory Quality					0.047			0.021	0.047
					(2.31)*			(0.55)	(1.18)
Inflation						-0.183		-0.168	-0.005
						(2.67)**		(2.11)*	(0.07)
Average years of schooling							0.011	0.002	0.004
							(1.88)+	(0.25)	(0.50)
LAC Dummy									-0.125
									(3.58)**
Observations	76	75	73	73	76	73	76	66	66
R-squared	0.05	0.00	0.03	0.07	0.07	0.06	0.05	0.15	0.29

Notes:
+ significant at 10%; * significant at 5%; ** significant at 1%.
Absolute value of robust t statistics in parentheses.
All regressions include a constant not reported here.
The dependent variable is TFP growth (in logs) between 1995 and 2005. All explanatory variables refer to initial 1995 values. For Trade/GDP, FDI/GDP, credit/GDP and inflation, average values between 1990 and 1994 from World Development Indicators are used. Regulatory Quality is the 1996 value of the index reported by Kaufmann *et al.* (2009). The technological creation index comes from Archibugi and Coco (2004), while average years of schooling refer to the average for the population older than 15 years from the Barro and Lee (2000) dataset.

Column 1 shows that an index of technological creation index by Archibugi and Coco (2004), which basically reflects patents granted per million population in the United States and scientific publication per million population (i.e. knowledge outcome variables). Interestingly, TFP growth is positively and significantly correlated with this index. The implied magnitude is economically significant too; a one-standard-deviation improvement in the index (e.g. increasing from the level of Chile or Argentina to that of France) would imply an increase by 0.3 percentage points in the annual TFP growth rate.

Next, we consider two variables often related to international diffusion of knowledge: global trade and FDI links (for a survey see Keller, 2004). While we do not find a significant correlation with trade openness, FDI shows a significant and positive correlation with TFP growth. The quantitative effect is similar to that of technological activity: a one-standard-deviation increase boosts annual TFP by 0.2 percentage points. While for private credit, we do not find a significant effect, we do so in the case of the regulatory quality, macro instability and uncertainty (proxied by the inflation rate) and human capital to analysis the capacity to absorb technologies. Again, in terms of economic magnitudes an improvement in any of these variables yields a similar effect on TFP growth of around an additional 0.3 percentage points per annum.

Table 2. **TFP levels and explanatory variables (2005)**

Variable	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
UNCTAD Technology Index	1.301							0.445	0.431
	(7.59)**							(1.91)+	(1.66)+
Trade/GDP (%)		0.001						-0.001	-0.001
		(1.20)						(0.53)	(0.50)
FDI/GDP (%)			0.035					0.020	0.020
			(1.18)					(0.59)	(0.58)
Private Sector Domestic Credit GDP				0.007				0.001	0.001
				(4.85)**				(0.74)	(0.72)
Regulatory Quality					0.393			0.216	0.220
					(6.56)**			(1.99)+	(1.85)+
Inflation						-0.988		-0.093	-0.072
						(2.06)*		(0.37)	(0.27)
Average year of schooling							0.11	0.027	0.028
							(8.99)**	(0.96)	(0.98)
LAC Dummy									-0.016
									(0.14)
Observations	76	75	73	73	76	73	76	66	66
R-squared	0.36	0.01	0.02	0.34	0.37	0.10	0.42	0.52	0.52

Notes:
+ significant at 10%; * significant at 5%; ** significant at 1%;
Absolute value of robust t statistics in parentheses.
All regressions include a constant not reported here.
The dependent variable is TFP growth (in logs) between 1995 and 2005. All explanatory variables refer to initial 1995 values. For Trade/GDP, FDI/GDP, credit/GDP and inflation, average values between 1990 and 1994 from World Development Indicators are used. Regulatory Quality is the 1996 value of the index reported by Kaufmann *et al.* (2009). The technological creation index comes from Archibugi and Coco (2004), while average years of schooling refer to the average for the population older than 15 years from the Barro and Lee (2000) dataset.

When all factors are considered jointly, all of them, except for inflation, lose their significance, probably due to multicollinearity problems. Of course, this simple exercise is too limited to identify causal links, but nevertheless it is interesting to point out that all eight variables (including the initial TFP level) explain only 15 per cent of the total variation in TFP growth rates across countries.[16] Thus, the correlates suggested by economic theory explain only a little part of the dispersion in growth rates. In particular, as column 9 of Table 1 shows, the low growth of TFP during this period in Latin America and the Caribbean is not explained by these correlates. When we include a dummy for the region, it is negative and highly significant, showing that the region's underperformance is not captured by the variables considered.

In Table 2, we follow a similar approach, but considering TFP levels instead of growth rates. As the results show, there is a positive and significant correlation between TFP levels and technological activity, the availability of domestic credit, regulatory quality, macroeconomic stability and human capital. When we include all of them together, only the technology index and institutions remain significant at a 10 per cent level.

It is interesting to point out that – in contrast to TFP growth rates – the correlates seem to explain a large fraction of the cross-country variation in TFP levels. R&D related activities, credit, institutions and human capital "explain" over 30 per cent of the variation considered one-by-one. The correlates explain jointly over 50 per cent.[17]

This evidence coincides also with Klenow and Rodríguez-Clare (2005) who find that R&D spending as a share of GDP correlates positively with income per capita and TFP levels, but there is no significant correlation with TFP and income growth.[18] They argue that the fact that income and TFP levels – rather than growth rates – are more correlated to investment and R&D expenditure, combined with the observed large co-movement in growth rates, is evidence in favour of endogenous growth models with international knowledge spillovers. Furthermore, it is interesting to point out that the dummy for LAC is not significant when included with all other explanatory variables. Based on column 8, the differences in R&D activity would account for around 38 per cent of the difference in TFP between the average OECD country and the average Latin American country in our sample, while differences in the institutional quality would account for around 26 per cent.

As mentioned above, our measure of TFP would also contain differences in the quality of education across countries. While international comparable data on the quality of human capital is difficult to have, we can use PISA scores as a proxy of it.[19] In particular, in Figure 10 we plot

16 This contrasts with the much higher R-squares commonly reported in cross-country growth regressions (see e.g. chapter 12, Barro and Sala-i-Martin, 2004).

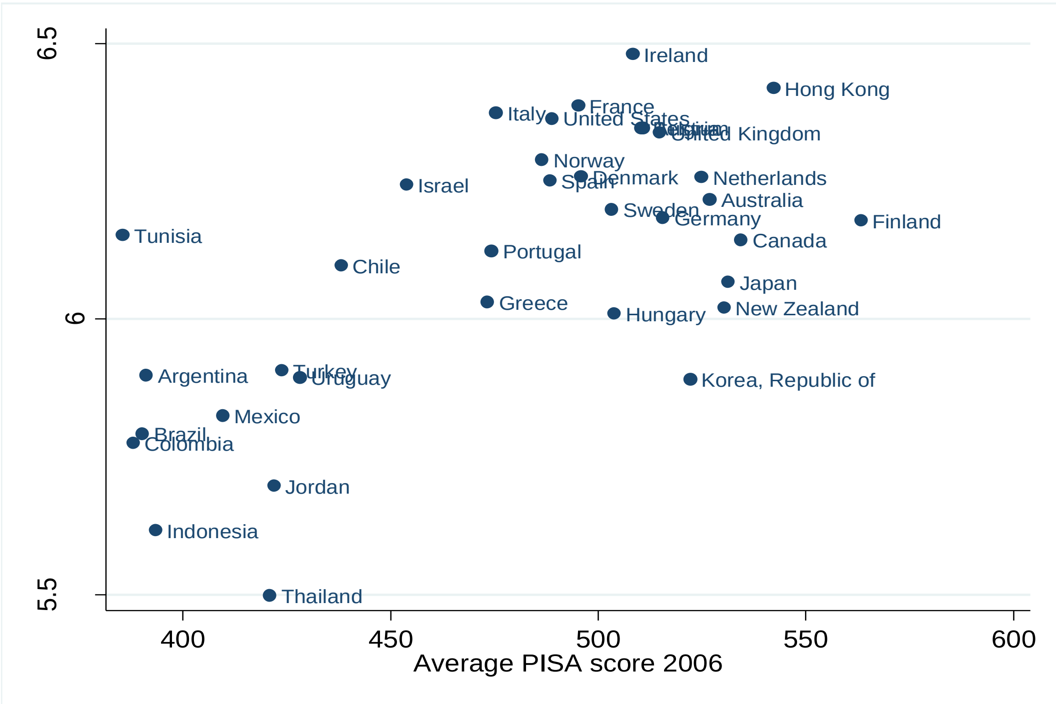
17 Of course, many of these variables could clearly be endogenous. For example, in most models of endogenous human capital, investment in human capital is an increasing function of the level of productivity. Similar arguments can be raised for R&D, or the demand for credit.

18 They also present similar evidence regarding physical investment. Investment ratios are stronger correlated with income per capita (across countries and time) than with the corresponding growth rates.

19 The OECD Programme for International Student Assessment (PISA) is "an internationally standardized assessment that was jointly developed by participating countries and administered to 15-year-olds in

the average score in the test for 2006 against the TFP levels for 2005. There is a positive correlation (with a coefficient of 0.65), such that as pointed out above, differences in the quality of human capital might well be included in our measure of TFP. This seems to be in line with Hanushek and Woessmann (2009) who argue that the low quality of education is one of the drivers of low GDP per capita growth in Latin America. However, PISA scores are not significant when included in multiple regressions like those shown in Table 2. Furthermore, from quantitative viewpoint, Caselli (2005) shows that the differences in the quality of education have to be unreasonable large in order to explain a significant fraction of the observed TFP gaps.

Figure 10. **TFP levels and PISA scores**



Source: Own calculations based on Daude and Fernández-Arias (2010) and OECD PISA 2006 report.

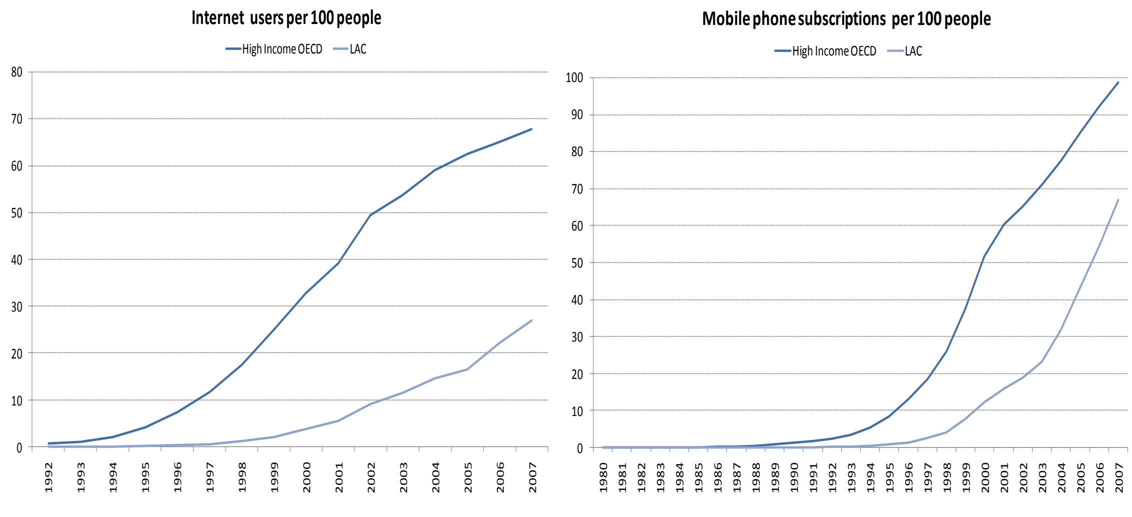
III.2. Evidence from the diffusion of new technologies

In this subsection, we analyse the diffusion of new technologies, to explore further the issue of whether countries in the region have a problem in terms of absorption capacity or whether framework conditions reduce aggregate efficiency through less diffusion. In particular, we consider the use of the internet and mobile phone technologies. Figure 11 shows the evolution of internet users per 100 people and mobile phone subscriptions per 100 people for High Income OECD (HI-OECD) countries and Latin America and the Caribbean (simple

schools. PISA assesses how far students near the end of compulsory education have acquired some of the knowledge and skills that are essential for full participation in society. In all cycles, the domains of reading, mathematical and scientific literacy are covered not merely in terms of mastery of the school curriculum, but in terms of important knowledge and skills needed in adult life." (for more details see http://www.oecd.org/department/0,3355,en_2649_35845621_1_1_1_1_1,00.html) averages). As shown in the left-hand panel, there is a considerable gap in the diffusion of internet usage between both regions. As of 2007, the average LAC country is at a state similar to the average HI-OECD almost ten years ago, with a user rate of almost 30 per cent versus almost 40 per cent in HI-OECD. Furthermore, the slopes do not indicate any increased speed in the adoption of the internet in the last couple of years. This contrasts with the situation of mobile phones, where the region seems to be catching up rapidly with HI-OECD countries. Of course, this difference might be due to a large variety of factors. For example, the cost involved in the access to the internet might be larger than buying a mobile phone. Furthermore, the required skills to operate a personal computer might be higher than the skills needed to master cell-phones technologies.

It is important to point out that in principle the diffusion and adoption of these new communication technologies could have limited impact on economic growth and development if they are just standard consumption goods that do not increase the efficiency of labour or the flow of information. However, there is some recent evidence that broadband internet as well as mobile phones have a significantly positive impact on economic growth. Qiang *et al.* (2009) find that a 10 per cent increase in broadband penetration increases growth by around 1.4 percentage points, while for mobile phones the impact is somewhat smaller: 0.6 percentage points of additional GDP growth given an increase of 10 per cent in the penetration rate for developing countries, according to Waverman *et al.* (2005).

Figure 11. **Comparative diffusion of new technologies across regions**



Source: World Development Indicators database.

Next, we analyse the determinants of the diffusion of these relatively new technologies, considering an empirical model similar to Chong and Micco (2003) that includes the variables used in our analysis of TFP determinants and some additional variables of interest that have been indicated in the economic literature to have an impact on technological diffusion.

Table 3 presents the estimates for the case of internet usage. The results show that human capital plays a significant role under all specifications considered. For example, the estimates in column 1 imply that a one-standard-deviation increase in the average years of schooling in the population (a change that would bring Paraguay to Argentina's level) is associated with an 8.4 percentage point increase in the percentage of internet users in the population. Another relevant variable is the availability of funding. Domestic credit to the private sector as a share of GDP is significant in all specifications, and implies that a one-standard-deviation increase in financial development leads to a 5-6 percentage point increase in internet usage. Meanwhile, trade and FDI exposure, as well as market size (GDP) and macro stability do not have a significant impact on the diffusion of the internet across countries. Overall, the results in general are in line with a recent study by Chinn and Fairlie (2010) on this issue, in terms of the factors that matter to explain the internet diffusion gap.

Table 3. **Determinants of internet users per 100 inhabitants (2006)**

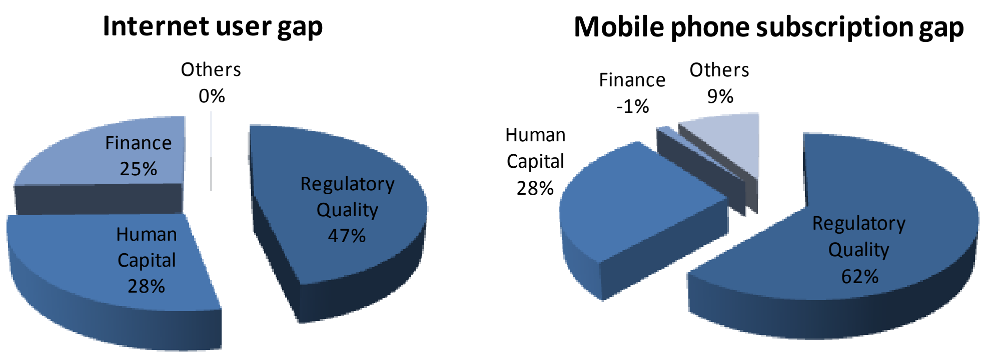
Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
GDP (log)	0.222	-0.457	0.012	0.820	0.210	-0.552	-0.061	0.850
	(0.29)	(0.60)	(0.02)	(1.01)	(0.27)	(0.70)	(0.08)	(1.04)
Average years of schooling	3.020	1.942	1.579	2.927	3.094	1.998	1.615	2.877
	(4.22)**	(2.09)*	(1.71)+	(4.04)**	(3.93)**	(2.11)*	(1.70)+	(3.52)**
Domestic credit to private sector/GDP (%)	0.122 (2.31)*	0.119 (2.27)*	0.101 (1.94)+	0.109 (2.08)*	0.120 (2.26)*	0.114 (2.15)*	0.099 (1.89)+	0.110 (2.07)*
FDI/GDP (%)	0.543	0.529	0.403	0.493	0.574	0.596	0.437	0.471
	(1.23)	(1.26)	(0.85)	(0.96)	(1.36)	(1.48)	(0.96)	(0.98)
Trade/GDP (%)	-0.03	-0.041	-0.035	-0.027	-0.031	-0.044	-0.037	-0.026
	(1.18)	(1.63)	(1.32)	(0.91)	(1.23)	(1.74)+	(1.38)	(0.91)
Inflation	11.544	8.543	6.559	13.315	14.251	14.279	9.166	11.548
	(0.42)	(0.34)	(0.23)	(0.44)	(0.49)	(0.53)	(0.31)	(0.37)
Regulatory Quality	11.301	9.285	7.417	9.896	11.162	8.770	7.307	9.915
	(3.84)**	(3.40)**	(2.96)**	(3.39)**	(3.66)**	(3.17)**	(2.90)**	(3.35)**
GDP per capita (log)		4.686	5.705			5.161	5.888	
		(2.26)*	(2.87)**			(2.28)*	(2.75)**	
Procedures to start a business			-0.872 (2.31)*	-0.764 (1.92)+			-0.822 (1.92)+	-0.797 (1.79)+
LAC dummy					-1.282	-2.860	-1.130	0.707
					(0.40)	(0.88)	(0.31)	(0.19)
Observations	93	93	89	89	93	93	89	89
R-squared	0.82	0.83	0.84	0.83	0.82	0.83	0.84	0.83

Notes:
+ significant at 10%; * significant at 5%; ** significant at 1%;
Absolute value of robust t statistics in parentheses.
All regressions include a constant not reported here. Notes: All explanatory variables refer to averages between 2001 and 2005, with the exception of Average years of schooling which refers to 1999 data. Procedures to start a business come from the World Bank's Doing Business database (www.doingbusiness.org). See Table 1 or 2 for the remaining variables.

Institutional factors seem to be the most important to understand the different patterns in internet usage. The quality of regulations has a statistically and also economically significant impact, implying an increase by around 10 percentage points if regulations are improved by one standard deviation (e.g. improving from Peru's level to that of Spain). Furthermore, the costs of starting a business – proxied by the number of procedures to start a business – have also a significant effect, although the quantitative implications are smaller, with a one-standard-deviation reduction implying an increasing in the internet usage rate of around 3 percentage points.[20] Finally, when including a dummy for LAC, we do not find it to be significant. This implies that the model – which has a very good overall fit – does a good job in explaining the average gap between the region and the rest of the world. This result contrasts with Chong and Micco's finding of a positive and significant residual for LAC countries for the late 1990s.

In the left-hand-side panel of Figure 12, we show a decomposition of the gap in internet penetration rates between OECD and LAC countries based on equation (1) in Table 3. As shown, the quality of regulations explains almost 50 per cent of the gap, while human capital and access to finance explain each around a quarter of the gap.

Figure 12. **Decomposition of gaps between OECD and LAC countries**



Source: Own calculations based WDI, Doing Business and Barro-Lee datasets.

In Table 4, we present the equivalent estimates for mobile phones, which show some interesting differences compared to the case of internet users. First, although human capital is significant in some specifications, once controlling for the level of development (GDP per capita) it loses its significance. Second, financial development does not have any significant effect on mobile phones. Third, there is some evidence that global linkages (trade) has a positive effect on mobile phone penetration, although the effect is rather small (an increase of trade to GDP by 10 percentage points increases the penetration rate of mobile phones by 0.7 percentage points). Finally, regulation and institutional aspects seem to be one of the main drivers of the cross country differences in mobile phone subscriptions. In particular, as shown in the right-hand-side panel of Figure 12, the quality of regulations explains 62 per cent of the remaining gap in mobile phone subscriptions between the OECD and LAC countries, while human capital differences explain around 30 per cent. As already mentioned, in contrast to the case of the internet, access to finance does not play a significant role.

20 While it could be argued that multicollinearity is a problem here, given that this variable might be correlated with regulatory quality and *GDP per capita*, even excluding these two variables, raises the effect just to 4.5 percentage points. Actually, the correlation with *GDP per capita* and *Regulatory Quality* is "just" -0.39 and -0.52, respectively.

Although the results imply – as expected – that the different drivers of technology adoption across technologies have a varying degree of importance, they are in line with the evidence presented by Comin and Hobijn (2004). They find – for a sample of 20 technologies in 23 advanced economies – that human capital is a major determinant of the speed of technology adoption. Furthermore, they also find that institutional variables (effectiveness of the executive and legislative) have a significant effect. The importance of institutions is also highlighted by Comin and Hobijn (2009), who find that technologies that compete with a preceding technology experience less rapid diffusion in economies with high barriers to competition and weak institutions.

Table 4. **Determinants of mobile phone subscriptions per 100 inhabitants (2006)**

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
GDP (log)	2.409	-0.924	-1.166	1.905	2.423	-0.871	-1.217	2.124
	[1.77]+	[0.85]	[1.03]	[1.34]	[1.79]+	[0.79]	[1.02]	[1.46]
Average years of schooling	4.13	-1.562	-0.478	4.936	3.615	-1.584	-0.456	4.500
	[3.10]**	[1.13]	[0.36]	[4.07]**	[2.91]**	[1.14]	[0.35]	[3.79]**
Domestic credit to private sector/GDP (%)	-0.009	-0.033	-0.018	0.021	0.009	-0.028	-0.019	0.028
	[0.10]	[0.45]	[0.26]	[0.25]	[0.10]	[0.39]	[0.27]	[0.33]
FDI/GDP (%)	0.575	0.487	0.432	0.793	0.321	0.435	0.462	0.560
	[0.72]	[0.74]	[0.71]	[0.94]	[0.46]	[0.70]	[0.77]	[0.73]
Trade/GDP (%)	0.065	0.009	0.025	0.06	0.077	0.012	0.023	0.069
	[1.59]	[0.20]	[0.62]	[1.49]	[1.93]+	[0.28]	[0.57]	[1.75]+
Inflation	14.531	-0.942	19.313	45.596	-6.134	-5.02	21.45	28.802
	[0.24]	[0.03]	[0.53]	[0.76]	[0.10]	[0.14]	[0.61]	[0.48]
Regulatory Quality	20.829	10.758	12.801	22.316	21.669	11.085	12.734	22.317
	[4.84]**	[3.04]**	[3.73]**	[5.12]**	[5.15]**	[3.03]**	[3.62]**	[5.16]**
GDP per capita (log)		24.446	22.773			24.077	22.933	
		[7.06]**	[6.89]**			[6.58]**	[6.50]**	
Procedures to start a business			1.235	1.634			1.277	1.311
			[2.17]*	[2.14]*			[2.01]*	[1.55]
LAC dummy					10.148	2.117	-0.949	6.862
					[1.98]+	[0.47]	[0.19]	[1.20]
Observations	91	91	87	87	91	91	87	87
R-squared	0.75	0.86	0.86	0.77	0.76	0.86	0.86	0.78

Notes:
+ significant at 10%; * significant at 5%; ** significant at 1%;
Absolute value of robust t statistics in parentheses.
All regressions include a constant not reported here.
All explanatory variables refer to averages between 2001 and 2005, with the exception of Average years of schooling which refers to 1999 data. Procedures to start a business come from the World Bank's Doing Business database (www.doingbusiness.org). See Table 1 or 2 for the remaining variables.

IV. OTHER DEVELOPMENT DIMENSIONS: LIFE EXPECTANCY CONVERGENCE

Another lens through which the link between development and innovation can be analysed is to look at changes in life expectancy across countries. In particular, the issue of how much of the region's TFP gap is due to a genuine lack of absorption capacity can potentially be benchmarked by a country's performance in terms of life expectancy relative to the frontier.[21] As pointed out by Becker *et al.* (2005), while the economic literature generally concentrates on the average "quality" of life (measured by GDP per capita), longevity implies also *more* life. These authors show that the economic value of increased life expectancy is quantitatively important. Once this aspect is taken into account in a comprehensive measure of welfare, there is much more convergence across countries than in GDP per capita.[22] Soares (2009) provides a similar analysis with focus on Latin America. He finds also large gains (similar in size to GDP growth from 1960 to 2000) from reduced mortality and longer life spans in the region.

Although there is a positive association between income and life expectancy,[23] for a fixed level of income life expectancy has been increasing.[24] This autonomous shift in life expectancy (as shown in Figure 13), joint with the fact most of the R&D in the area of medical research and equipment is done in a reduced number of countries,[25] and the fact that health investments are larger (in absolute and relative terms) in developed countries,[26] point all to the importance of technological progress and knowledge spillovers as a major driver of the reduction in mortality around the world. Of course, catch-up due to low initial investments in health also plays a role, but as Becker *et al.* (2005) argue, returns to health investments in low-income countries would have to be extremely large if the observed patterns (discussed more in detail below) of reductions in mortality were to be explained just by capital deepening in health production.

21 Life expectancy is also one of the four indicators (in addition to adult illiteracy, school enrolment and GDP per capita) included in the UN's Human Development Index.

22 The exception to this fact is Sub-Saharan Africa since the 1990s, due to the high prevalence of HIV/AIDS.

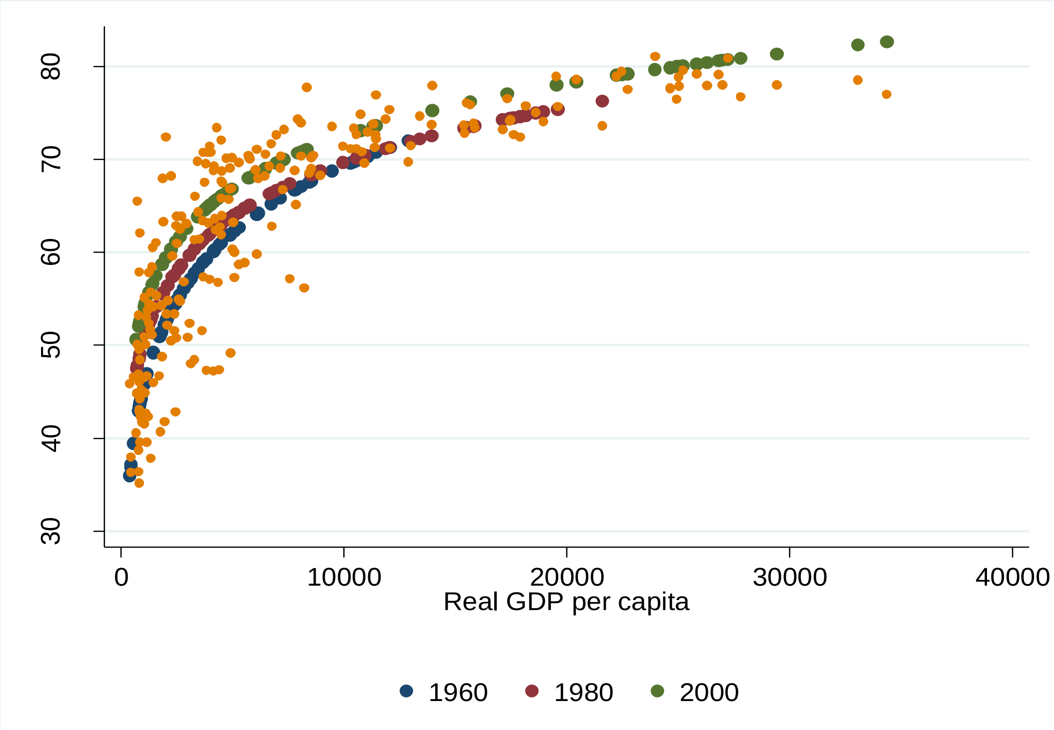
23 As Soares (2007, 2009) points out, this probably is mainly due to the impact of income on nutrition.

24 This fact was first presented by Preston (1975).

25 For example, according to OECD figures, as of 2002 almost 85 per cent of the OECD's R&D expenditure in the pharmaceutical sector was concentrated in just five countries (France, Germany, Japan, the UK and the US).

26 According to *World Health Organization*'s statistics while the average per capita public health expenditure in Latin America and the Caribbean is around USD 320 (in PPP terms), for OECD countries this average is more than six times Latin America's (around USD 2 100). Data are available at: http://www.who.int/whosis/en/index.html

Figure 13. **Predicted relationship between life expectancy and income per capita by decade**



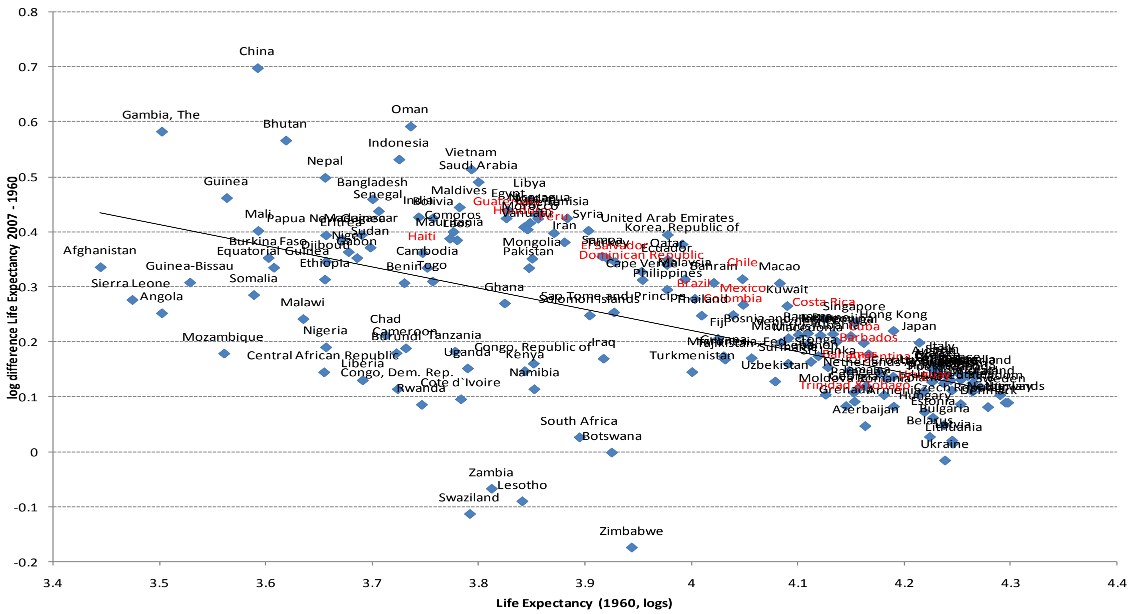
Source: Own calculation based on Penn World Tables version 6.2 and World Development Indicators.

As shown in Figures 14 and 15, there is clear evidence of unconditional "beta" convergence (life expectancy has risen more in countries where its initial level was lower) as well as "sigma" convergence (the dispersion across countries in life expectancy is decreasing over time) in life expectancy for a panel of 170 countries over the long-run (1960-2007). There is a significantly negative correlation between the initial level of life expectancy and the subsequent increase in life expectancy, which shows that on average there is catch up. Similarly, the dispersion across countries in life expectancy is decreasing over time, once high HIV/AIDS countries in Sub-Saharan Africa (SSA) are excluded. The implied average speed of convergence is of around 1 per cent per annum. Of course, there is also some evidence of convergence by clubs, as documented by Mayer-Foulkes (2001) and Ram (2006), but LAC countries are usually in the high life expectancy group.

Furthermore, Figure 14 also shows that countries in LAC have been part of this convergence process – contrary to their experience regarding income per capita and TFP. **Thus, the potential puzzle is why technological change in the health sector seems to spread more easily than knowledge in other productive activities in LAC**.

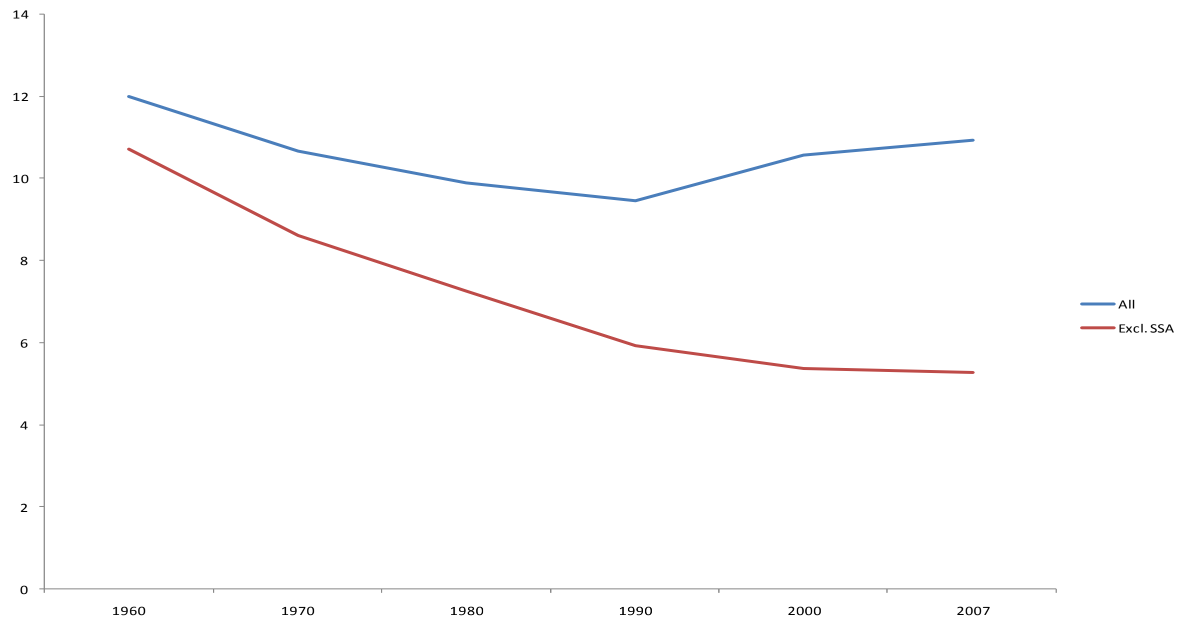
As Soares (2007) points out, the diffusion of knowledge and ideas in the health sector has some particularities in comparison to diffusion of technologies in other sectors. First, health is primarily an outcome of household decisions, such that technology requires the absorption on behalf of the final user rather than just embodied technological change, especially at low levels of development. Second, market failures, externalities and public good dimensions are especially severe in the sector. In this sense, as Cutler *et al.* (2006) point out, progress in health tends to be associated with a country's "…ability and political willingness to implement known technologies" (p. 116). It seems that vested interests that seem to play an important role in holding back this process in the region tends to be less severe than in other productive sectors of the economy, in part probably due to the public's sensitivity to health issues.

Figure 14. **Beta convergence in life expectancy**



Source: Own calculations based on World Development Indicators.

Figure 15. **Sigma convergence in life expectancy**



Source: Own calculations based on World Development Indicators.

In Table 5 and 6, we analyse the convergence speed and Latin America's relative performance in life expectancy. The first column basically reproduces the regression presented in Figure 14, which shows a significant convergence term. In column 2, we focus on the more recent period since 1980. As it can be seen, the speed of convergence for this period is significantly slower than for the whole period. From a convergence speed of almost 1 per cent per annum, it declined to a quarter per cent. As shown in columns 3 and 4, the magnitude of this decline is not entirely driven with countries with high HIV/AIDS incidence. Furthermore, if the model is estimated only for the 96 countries that have data for the 1960s, the estimated convergence coefficient is very similar to that of the larger sample (see column 5). Thus, the reduction in convergence is probably due to a more global trend.

Table 5. **Life expectancy convergence regressions (OLS)**

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Period	2007-1960	2007-1980	2007-1960	2007-1980	2007-1980	2007-1960	2007-1980
Sample	All	All	Excl. high HIV/AIDS countries	Excl. high HIV/AIDS countries	Information available for 1960	All	All
Initial Life Expectancy (log)	-0.361	-0.114	-0.413	-0.165	-0.106	-0.49	-0.13
	(7.71)**	(2.77)**	(9.31)**	(4.25)**	(2.07)*	(6.43)**	(1.87)+
Initial GDP per capita (log)	-	-	-	-	-	0.038	0.003
						(1.85)+	(0.28)
Constant	1.674	0.567	1.901	0.791	0.532	1.89	0.606
	(8.62)**	(3.24)**	(10.33)**	(4.84)**	(2.46)*	(9.19)**	(2.74)**
Observations	96	145	90	136	96	96	145
R-squared	0.32	0.04	0.51	0.14	0.04	0.34	0.04
Speed of convergence (per annum)	0.95%	0.26%	1.13%	0.38%	0.24%	1.43%	0.30%

Notes: The dependent variable is the log difference between life expectancy in 2007 and 1960 or 2007 and 1980.
+ significant at 10%; * significant at 5%; ** significant at 1%;
Absolute value of robust *t*-statistics in parentheses.

Table 6 explores whether LAC differs significant with respect to the average international pattern. We re-estimate the equations 1-4 from Table 5 and introduce a dummy variable for LAC countries. As the results show, in most specifications the LAC is positive and significant, such that LAC countries show on average a faster increase in its life expectancy than the rest of the world, even controlling for GDP per capita. When controlling for the number of physicians available (a proxy of the supply-side and available resources in the health sector), this variable has a positive and significant impact on life expectancy, as expected. However, the LAC continues to be significant, such that the region's good performance is not explained by its level of initial development and/or the efforts in terms of health care resources.

It could be argued that the increase in life expectancy is driven by the adoption of minimum immunisation and hygiene improvements – not very knowledge-intensive technologies – which in general have an important impact on infant mortality rather than increasing longevity. To control for this possibility, in the last column of Table 6 we include the change in infant mortality rates during the period 1960-2007. As expected the effect is negative and significant, such that a decrease in infant mortality has a positive effect on life expectancy. However, the LAC dummy continues to be positive and significant. Thus, it seems that a relatively high absorption of technologies is a likely candidate to explain this performance. Nevertheless, it should be pointed out that East Asian countries exhibited an even faster convergence rate, which confirms in this dimension the relatively faster convergence of the region in terms of GDP per capita and TFP as well.

Figure 14 shows the partial correlation between TFP growth and the residual of life expectancy growth controlling for initial levels of GDP, life expectancy and the number of physicians. There is a positive and significant correlation between both variables – with a correlation coefficient of 0.41 and a p-value of 0.005 – such that countries that experienced higher TFP growth also caught up in terms of life expectancy faster. Considering just LAC countries, this correlation is 0.39, although it is only marginally significant (p-value of 0.12). Thus, this is further evidence of improvements in the "quantity" of life seem to be driven by technological progress.

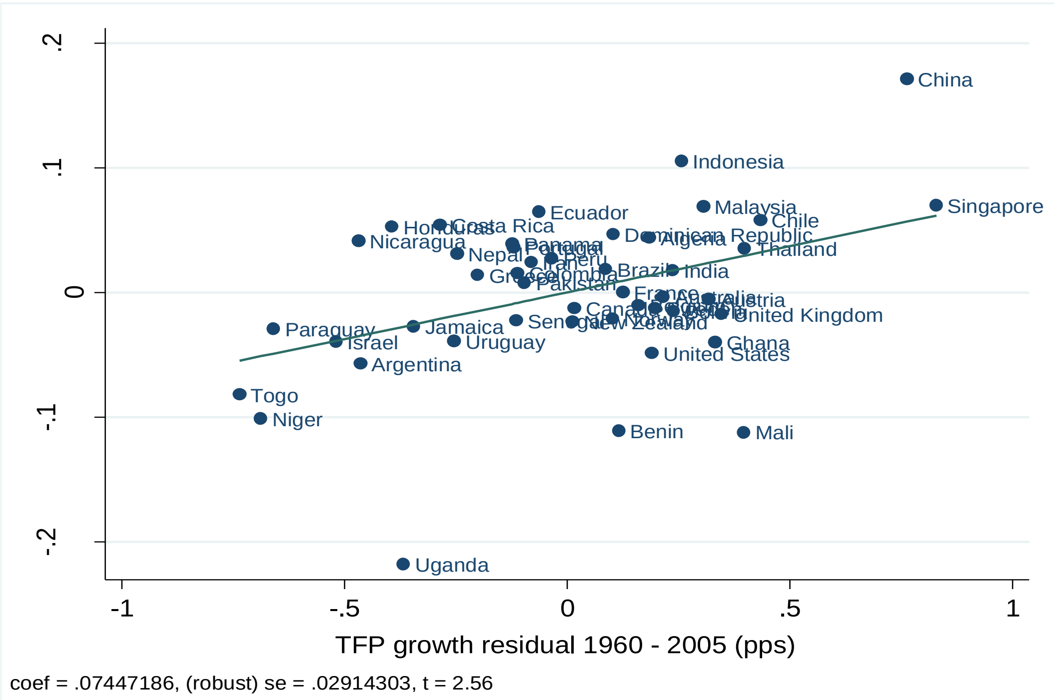
Table 6. **Life expectancy convergence LAC and additional controls (OLS)**

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Period	2007-1960	2007-1980	2007-1960	2007-1980	2007-1960	2007-1980	2007-1960
Sample	All	All	Excl. high HIV/AIDS countries	Excl. high HIV/AIDS countries	All	All	All
Initial Life Expectancy (log)	-0.489	-0.149	-0.500	-0.200	-0.572	-0.181	-0.815
	(6.49)**	(2.12)*	(8.72)**	(3.48)**	(5.16)**	(2.50)*	(7.89)**
Initial GDP per capita (log)	0.033	0.004	0.023	0.006	0.028	0.003	0.028
	(1.64)	(0.34)	(1.64)	(0.66)	(1.22)	(0.29)	(1.39)
LAC Dummy	0.056	0.033	0.038	0.015	0.071	0.035	0 .064
	(3.12)**	(2.51)*	(2.41)*	(1.41)	(2.98)**	(2.36)*	(3.35)**
Initial physicians per 1000 people					0.059	0.012	0.045
					(1.04)	(2.06)*	(1.10)
Change in infant mortality 2007 - 1960							-0.138
							(6.53)**
Constant	1.912	0.669	2.056	0.886	2.247	0.799	3.025
	(9.47)**	(3.04)**	(11.39)**	(4.63)**	(5.47)**	(3.49)**	(8.52)**
Observations	96	145	90	136	88	135	82
R-squared	0.37	0.05	0.54	0.15	0.37	0.06	0.65

Notes: The dependent variable is the log difference between life expectancy in 2007 and 1960 or 2007 and 1980.
+ significant at 10%; * significant at 5%; ** significant at 1%;
Absolute value of robust *t*-statistics in parentheses.

Overall, this section has shown that while in terms of GDP per capita LAC countries have been lagging behind, regarding another key aspect of development – life expectancy – the region's performance has been much better, although below potential, when compared to developing countries in East Asia. Furthermore, the evidence presented here points at the absorption of technological progress in the health sector as the driving force of this performance. Interestingly, this contrasts with the region's low absorption on the aggregate productive level, analysed in section III. A more detailed study of these issues is clearly needed, but the evidence presented here suggests that probably political economy factors that make the health sector less prone to barriers to technological progress.

Figure 14. **Partial correlation between changes in TFP and life expectancy**



Note: The graph shows the partial correlation between life expectancy growth and TFP growth, controlling for the log of GDP per capita in 1960, the number of physicians in 1960, initial level of life expectancy in 1960, excluding countries with high HIV/AIDS incidence.
Source: Own calculations based on PWT version 6.2 and World Development Indicators.

V. TFP GAPS AND INNOVATION SHORTFALLS

In this section we use a "varieties" endogenous growth model by Córdoba and Ripoll (2008) to analyse further the importance of productive factors versus aggregate inefficiencies to explain the relatively low levels of GDP per capita in LAC versus the frontier. In a quite similar way to Maloney and Rodríguez-Clare (2007), we use an endogenous growth model to calibrate some wedges and parameters and assess the contribution of low levels of innovation to the development gap in terms of GDP per capita. Basically, it is an attempt to put more structure on the developing accounting performed in section II, in order to infer more about the drivers of TFP and to account jointly for the endogeneity of factors and productivity.

V.1. The model economy

While a complete explanation and derivation of the model can be seen in Córdoba and Ripoll's paper, here we outline just the major ingredients necessary for our quantitative calibration exercises. Aggregate output (Y) is produced using a variety of inputs (x) using a CES aggregator:

$$Y_t = \left(\sum_{j=1}^{N_t} x_{jt}^{\gamma} \right)^{1/\gamma}, \quad 0 < \gamma < 1 \qquad (6)$$

where each intermediate good is produced using a Cobb-Douglas production function combining physical and human capital: $x_j = k_j^{\alpha} h_j^{1-\alpha}$.

Factor markets are assumed to be competitive, but new intermediate goods are produced under monopolistic competition. Market power disappears randomly following a Poisson process with parameter p, such that the expected lifetime of monopolistic power is given by $1/p$. Thus, this parameter can be interpreted as the degree of intellectual property rights protection. Afterwards, the variety is produced under competitive conditions, such that at all times there is a fraction of intermediate goods N_m produced under monopolistic conditions and a fraction $N_c = N - N_m$ produced under competitive conditions.

The cost of introducing a new variety is given by: $\lambda_t = N_t^{-\phi} \left(N_t^{*} \right)^{-\eta} L_t$. The first term captures externalities in the research process where the cost of innovation is a decreasing function of these externalities captured by the parameter $\phi > 0$. Furthermore, the cost R&D is also a decreasing function of the international frontier denoted by N^{*}, such that for countries that are far away from the frontier it is easier to adopt existing technologies. The linear dependence on the labour force is included to eliminate scale effects. Risk neutrality and free entry imply that innovators have to breakeven in expected terms, such that:

$$\lambda_t = \int_t^{\infty} \pi_m(v) e^{-(r+p)(v-t)} dv ,$$

where the right-hand-side is the present discounted value of expected profits.

In terms of frictions, the model assumes that returns on physical capital can be expropriated, such that a wedge (represented by q) between the return on capital (r_k) and the risk free interest rate on assets (r) is created: $1 + r = (1 + r_k - \delta)(1-q)$, where δ is the rate of depreciation.

Along the balanced growth path, Córdoba and Ripoll (2008) show that aggregate output is given by:

$$Y_t = K_t^{\alpha} \left(A_t^{\beta} H_t \right)^{1-\alpha} , \qquad (7)$$

where $A_t = \left[\left(\frac{g + \theta^{\gamma} p}{g + p} \right)^{1/\gamma} \frac{g + p}{g + \theta p} \right]^{\gamma / 1-\gamma} N_{t,} \quad \beta = \frac{1-\gamma}{\gamma(1-\alpha)}$.

The parameter θ is the ratio of intermediate goods produced by competitive versus monopolistic firms in equilibrium, and g is the growth rate of the frontier $A^* = N^*$. For TFP growth, we have that:

$$\dot{A}_t = d A_t^{\phi} \left(A_t^* \right)^{\eta} s_R y_t , \qquad (8)$$

where $d = \left[\left(\frac{g + \theta^{\gamma} p}{g + p} \right)^{1/\gamma} \frac{g + p}{g + \theta p} \right]^{\gamma(1-\phi) / 1-\gamma} ; \quad s_R = \frac{R}{Y}$.

Regarding the parameters, we assume that – to rule out strange dynamics – the following restriction holds: $1 - \phi - \beta = \eta$.

In terms of the physical capital, the equilibrium capital-output ratio of the model is given by:

$$\kappa = \alpha \gamma \frac{g + \theta p}{g + \theta^{\gamma} p} \frac{1-q}{r + q + \delta(1-q)} \qquad (9)$$

Finally, the remaining key equation is the R&D investment ratio, given by:

$$s_R = \frac{(1-\gamma) g}{r + p + (\phi + \eta) g - g_L} \frac{g + p}{g + \theta^{\gamma} p} \qquad (10)$$

These two last equations imply that increasing patent protection (lowering p) increases the R&D investment ratio but decreases the capital-output ratio, because an increase in p lowers the expected return on capital.[27] In addition, distortions to capital accumulation (q) have no effect on R&D investment ratios, but lower the capital output ratio (as obviously expected).

Based on these equations, output per worker can be decomposed according to a "pure" TFP component and a factor component:

$$y_t = \tilde{A}(p)\tilde{X}(p,q,h), \qquad (11)$$

where:

$$\tilde{A}(p) = \Omega(p)\left(\frac{(1-\gamma)d}{r+p+(\phi+\eta)g-g_L}\,\frac{g+p}{g+\theta^{\gamma}p}\right)^{\beta/\eta}\left(A_t^*\right)^{\beta} \qquad (12)$$

$$\tilde{X}(p,q,h) = \Omega(p)^{-1}\left[\left(\alpha\gamma\frac{g+\theta p}{g+\theta^{\gamma}p}\,\frac{1-q}{r+q+\delta(1-q)}\right)^{\frac{\beta}{\eta}} h\right]^{1+\frac{\beta}{\eta}} \qquad (13)$$

$$\Omega(p) = \left(\frac{g+p}{g+\theta^{\gamma}p}\right)^{\frac{\alpha}{1-\alpha}\left(1+\frac{\beta}{\eta}\right)} \qquad (14)$$

V.2. Calibration

The data regarding output per worker, physical and human capital are the same that we have used so far. Furthermore, as Córdoba and Ripoll (2008) we assume a risk free interest rate (r) of 2% and calibrate η to match a speed of convergence of 3 per cent per annum (such that η=0.5), which represents an intermediate value of estimates reported by Parente and Prescott (1994). We use Klenow and Rodríguez-Clare (2005) for parameter values of α=1/3, β=0.21, δ=0.08, g=0.015 and g_L=0.011, respectively. The parameters ϕ and γ are deduced from the values of α, β and η, such that ϕ = 0.09 and γ =0.75.

There are of course different ways to obtain p and q. In what follows, we present two different alternatives. Under the first alternative, we assume that the observed R&D expenditure to output ratios correspond to the real alternatives equation (10) and following Córdoba and Ripoll by assuming that for the frontier (US) with a value of p^* equal to 1/100, the patent protection parameter p can be inferred from:

$$\frac{s_R}{s_R^*} = \frac{r+p^*+(\phi+\eta)g-g_L}{r+p+(\phi+\eta)g-g_L}\,\frac{g+p}{g+\theta^{\gamma}p}\,\frac{g+\theta^{\gamma}p^*}{g+p^*} \qquad (15)$$

The using p in equation (9), we can solve for q. We refer to this procedure as "Calibration 1" in from here on.

Under the second alternative (Calibration 2, henceforth) – the one followed by Córdoba and Ripoll (2008) – we can calibrate p from equation 12 if the frontier A^* is known. We assume that the maximum value of TFP in our sample for the year 2005 (computed using equation 2) is

[27] However, if g is close to zero, then the effect of p on the capital-output ratio will be very small.

associated with a value of p equal to 1/100. Then, we can solve for the frontier and calibrate p for each country using (12). Given the value of p we can infer q from equation (13).

V.3. Main results

The first interesting result is to consider the decomposition of output per worker implied by equation (11) for the case of LAC. In particular, as shown in Table 7, once we take into account the endogeneity of TFP to factor accumulation, TFP explains on average around 39 per cent of the income per worker gap with respect to the US for the average LAC country in 2005 using Calibration 1 and 40 per cent for Calibration 2, with factors explaining the remaining 61 and 60 per cent, respectively. At least in the aggregate, it seems that both calibrations result in quite similar decompositions. Under both methods, while on average factors seem to be more important, TFP inefficiencies are still significant.

Table 7. **Contribution to Incomer per worker gap in 2005 with the US (endogenous TFP)**

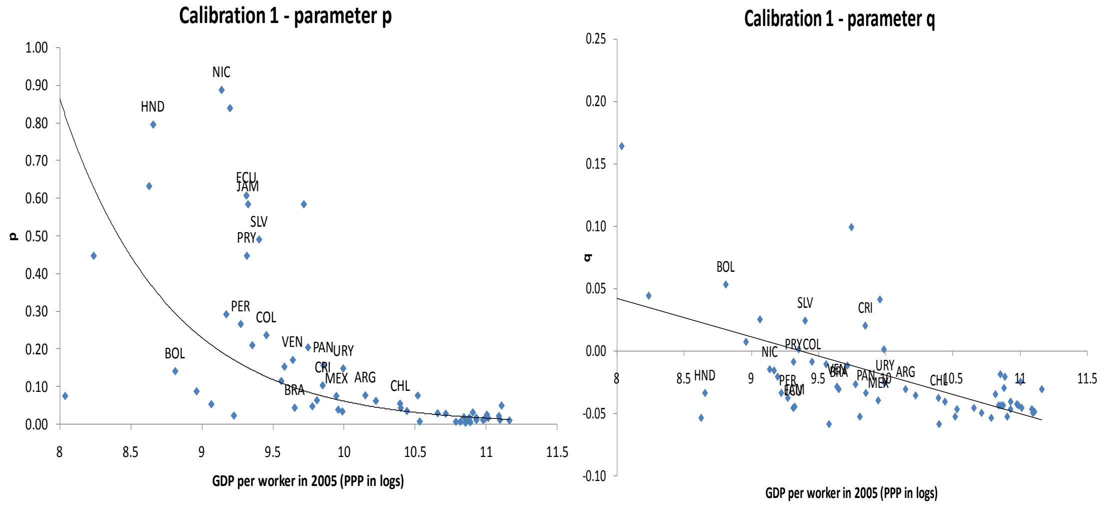
Country	*Calibration 1*		*Calibration 2*	
	TFP	*Factors*	*TFP*	*Factors*
Argentina	0.42	0.58	0.46	0.54
Bolivia	0.38	0.62	0.39	0.61
Brazil	0.30	0.70	0.31	0.69
Chile	0.19	0.81	0.25	0.75
Colombia	0.22	0.78	0.25	0.75
Costa Rica	-0.07	1.07	-0.02	1.02
Dominican Republic	-	-	0.08	0.92
Ecuador	0.57	0.43	0.59	0.41
Honduras	0.53	0.47	0.55	0.45
Jamaica	0.46	0.54	0.48	0.52
Mexico	0.44	0.56	0.47	0.53
Nicaragua	0.32	0.68	0.34	0.66
Panama	0.50	0.50	0.53	0.47
Peru	0.64	0.36	0.66	0.34
Paraguay	0.32	0.68	0.35	0.65
Uruguay	0.30	0.70	0.34	0.66
Venezuela	0.41	0.59	0.44	0.56
Average (geometric mean)	**0.39**	**0.61**	**0.40**	**0.60**

Source: Own calculations based on PWT version 6.2, World Development Indicators, and Daude and Fernández-Arias (2010).

Furthermore, Table 7 also shows that there is a lot of heterogeneity among countries in the region, although the patterns remain similar to those discussed in Figure 7. For example, in the cases of Costa Rica, Dominican Republic, Chile, Colombia, and to some extent Brazil, Uruguay, Nicaragua and Paraguay, the main problem seems to be a low level of factors rather than TFP. Thus, once we take into account that TFP accumulation is endogenous to factors, it becomes clear that for many countries in the region insufficient factor accumulation is a relevant issue to explain the prevailing income gaps. However, it should be noticed that considering the possibility that human capital investment might react to TFP would probably again increase the balance in favour of TFP in several countries.

Exploring further the implications of the model, in Figures 15 and 16 we plot the resulting parameters for *p* and *q* under calibrations 1 and 2, respectively. There are a couple of interesting results in these graphs. First, under both calibrations, in general LAC countries present a parameter *p*, that is less protection of intellectual property rights, higher than expected given their GDP per worker. For Calibration 1, only Bolivia and Brazil are below the expected level, while for Calibration 2 this happens for El Salvador, Costa Rica and Dominican Republic.[28]

Figure 15. **Parameters *p* and *q* (Calibration 1)**

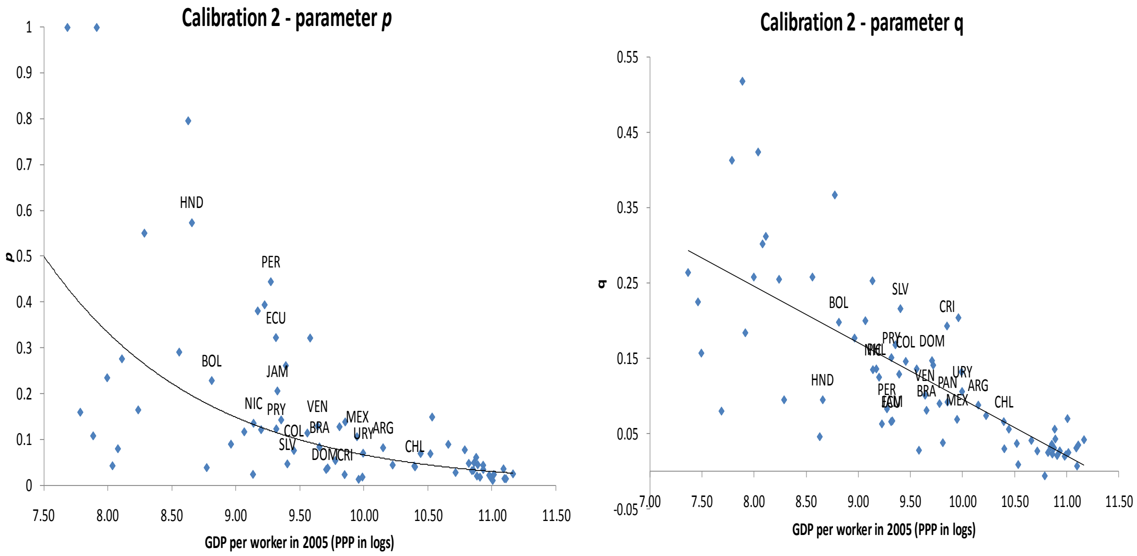


Source: Own calculations based on PWT version 6.2, World Development Indicators, and Daude and Fernández-Arias (2010).

In the case of the implicit tax on capital – or expropriation parameter – *q*, both parameterisations given a very similar ranking of the countries (the simple correlation coefficient between both alternative parameters is 0.95). However, under Calibration 1, most countries in the region exhibit negative implicit tax rates, while those that have positive rate, show moderate rate (e.g. Bolivia has a 5 per cent implicit tax rate). The reason for this fact is that the values for the parameter *p* are extremely high under Calibration 1. In contrast, for Calibration 2, the implicit tax rate for all countries is positive and much higher (e.g. Bolivia now would have a tax rate of around 20 per cent on capital).

28 An exponential function is fitted to the data, given that the parameter *p* is a probability and therefore bounded to lie between 0 and 1.

Figure 16. **Parameters *p* and *q* (Calibration 2)**



Source: Own calculations based on PWT version 6.2, *World Development Indicators*, and Daude and Fernández-Arias (2010).

These differences are probably due to fact that Calibration 1 relies on the observed R&D to GDP ratios to calibrate the parameters. These ratios are probably measured with considerable errors and they also do not include many informal R&D activities in developing countries that are not captured in the traditional R&D measures, in particular process innovation.[29] For these reasons, we will continue using the results from Calibration 2. Nevertheless, it is reassuring that the differences across parameters do not matter too much in terms of the decomposition exercises in Table 7 between TFP and factors.[30]

While the advantage of working with the region's average is mainly that it reduces measurement errors, from the analysis so far, it is clear that there are significant differences within the region. Figure 17 compares the parameters for the countries in the region with respect to the US and the average values for the rest of the world (ROW). This graph summarises several relevant results in terms of policy priorities.

First, in comparison to the frontier (US) all countries in the region (with the exception of Costa Rica in the *p* dimension) show higher levels of distortions in both dimensions – the implicit tax on capital and the protection of intellectual property rights.

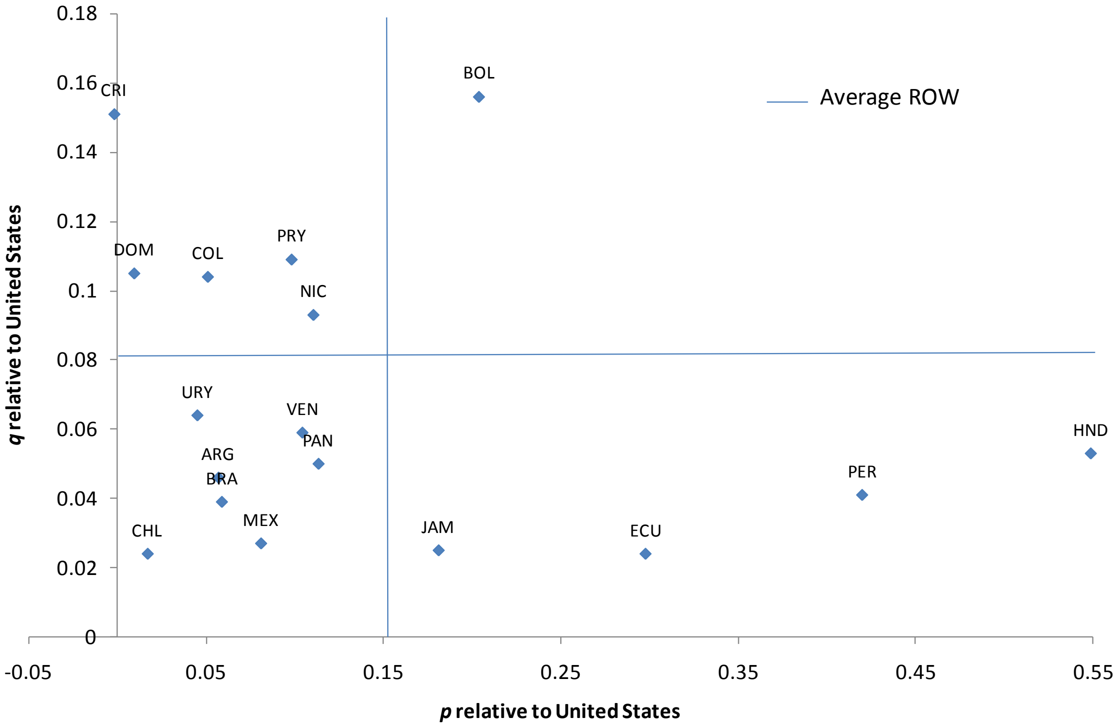
Second, taking the ROW as benchmark, there are four groups of countries with somewhat distinct problems. The lower right quadrant groups the countries (Ecuador, Honduras, Jamaica

29 Furthermore, the data do not include R&D in the primary sector, a sector that is very important for Latin America.

30 This might be so because the problem of R&D measurement is common to other countries in the sample, too. In particular, for the US *p* takes the values 0.01 and 0.024 for calibration 1 and 2, respectively, while *q* is -0.031 and 0.042, offsetting partially the effects of changes in *p* and *q* in LAC countries.

and Peru) that primarily have an important problem of innovation compared to the ROW. For this group of countries policies aiming at boosting productivity, the absorption of technology and innovation in a broad sense should be prioritised. The upper left group of countries includes countries (Colombia, Costa Rica, Dominican Republic, Nicaragua, and Paraguay) that mainly suffer from a low GDP per capita due to low private appropriability of factor returns. For these countries, reducing to the distortions to the accumulation of factors and probably providing public goods (e.g. infrastructure) that increase private profitability. In the lower left quadrant, there is a group of countries were both types of distortions are lower than the ROW with respect to the US, including Argentina, Brazil, Chile, Mexico, Panama, Uruguay and Venezuela. Certainly, this does not mean that these countries do not face any challenge regarding any of the two dimensions, but rather that there is no "smoking gun" in terms of which distortion is greater. While have not considered issues of heterogeneity in productivity across firms as a source of low aggregate output, policies that allow for more flexibility in the reallocation of inputs, as well as facilitate exit and entry of firms would probably serve these countries well, given that these countries are in general closer to the frontier that the rest of the region (see Acemoglu *et al.*, 2006).

Figure 17. **Benchmark analysis of the region for *p* and *q***



Source: Own calculations based on PWT version 6.2, World Development Indicators, and Daude and Fernández-Arias (2010).

VI. CONCLUSIONS

The present paper has analysed some of the causes behind the low levels of productivity and growth that have held back Latin America's economies. The development accounting exercises point towards TFP as the main factor behind its GDP per capita gap with respect to the frontier in most countries in the region, though the situation is far from homogeneous. Some of the evidence presented in the paper indicates that low levels of TFP and technology diffusion are due to weak regulatory frameworks and institutions, but that the absorption capacity – in particular human capital – also plays a non-negligible role, as do other framework conditions like the availability of finance. Furthermore, while the GDP per capita performance of the region has been mediocre, in terms of life expectancy the region has been more successful. This convergence seems to be driven in part by the ability to incorporate technological progress beyond rather simple improvements in hygiene and basic vaccinations. A question for future research is what explains this difference in outcomes between the production of goods and services and life expectancy. Political economy factors might explain the differences in barriers to technology adoption across sectors, but a rigorous analysis is needed to advance in our understanding of this empirical fact.

In terms of policy conclusions, it is clear that a "one size-fits-all" recommendation for the region would be erroneous, given that the causes for low productivity and technology diffusion differ significantly across countries in the region. For countries where restrictions on physical capital accumulation are severe, a reform agenda that increases the private returns to investment, e.g. improving property rights, but also providing key infrastructure, is the most relevant. In the case of countries that suffer from a high implicit tax on innovation, the priority should be to facilitate technology adoption, as well as the promotion of new economic activities (such as new exports) with high potential spillovers for the rest of the economy. At the same time, all countries would benefit from a higher absorption capacity via more investment in education (especially improving the quality of education). This policy would also have positive effects on the return to private investment. In any case, a much more in depth country-specific analysis is needed to advance in the definition of a development agenda that puts ideas and innovations to raise sustainable growth and productivity at its centre.

There are of course many issues that have been left out of the analysis and are specifically relevant for Latin America. Among them is definitely the role of commodities and the primary sector as an opportunity or a barrier to move to more knowledge-based growth in the region. Also, the role of trade and specialisation has not been addressed in depth. Finally, a deeper analysis of how distortions interact with entry and exit of heterogeneous firms is needed.

APPENDIX

The capital stock is constructed using the *Penn World Tables* 6.2 (see Heston *et al.*, 2006). Total investment in PPP terms is obtained by multiplying the PPP adjusted investment ratios to GDP (*ki*) by real GDP per capita (*rgdpl*) and the population (*pop*). Following the methodology presented in Easterly and Levine (2001) we use a perpetual inventory method to construct the capital stock. In particular, the capital accumulation equation states that:

$$K_t = K_{t-1}(1-\delta) + I_t \,, \qquad \text{(A.1)}$$

where K_t is the stock of capital in period t, I is investment and δ is the depreciation rate which we assume equals 0.07. From the capital accumulation equation (A.1) and assuming steady state conditions, we can compute the initial capital-output ratio as:

$$\frac{K_0}{Y_0} = \frac{i}{g+d} \,, \qquad \text{(A.2)}$$

where i is the average investment-output ratio for the first ten years of the sample (the 1950s), and g is a weighted average between a world growth (75 per cent) of 4.2 per cent and the average growth of the country for the first ten years of the sample (25 per cent). To obtain the initial capital stock K_0 we multiply the capital output-ratio from (3) by the average output of the first three years of the sample.[31]

For human capital, we follow Hall and Jones (1999) by constructing the index h as a function of the average years of schooling given by:

$$h = e^{\phi(s)} \,, \qquad \text{(A.3)}$$

where the function $\phi(.)$ is such that $\phi(0) = 0$ and $\phi'(s)$ is the Mincerian return on education. In particular, we assume that this function to be piece-wise linear. Based on Psacharopoulos (1994), we assume the following rates of return for all the countries: 13.4 per cent for the first four years of schooling, 10.1 per cent for the next four years, and 6.8 per cent for education beyond the

[31] Daude and Fernández-Arias (2010) present some robustness checks showing that from the 1970s onwards TFP measures are not very sensitive to initial conditions and assumptions.

eighth year. Finally, we compute the average by country using the data on years of schooling in the population from the Barro-Lee database.[32]

Output (Y) is given by PPP adjusted real GDP from the *Penn World Tables* 6.2.The data are available until 2004 and we extend the data to 2005 using PPP GDP growth reported by the World Bank's *World Development Indicators* (WDI).

Finally, the labour input is measured by the number of persons in the labour force from the WDI database.[33] In order to isolate short-run fluctuations in labour market participation from TFP measurement, we focus on HP-filtered trends, such that only permanent differences in unemployment rates, a failure to productively utilise available labour inputs, would affect relative TFP.

32 Clearly differences in the quality of human capital across countries could affect our measure of human capital. However, as Daude and Fernández-Arias (2010) show, if the differences in the quality of education are the same for all levels of education, they would be adequately captured in TFP comparisons.

33 Hours worked would probably be a more accurate indicator, but we do not consider it due to limited availability.

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