Human Capital Composition and Economic Growth at a Regional Level.

By Fabio Manca[1]

[1] UNIVERSIDAD DE BARCELONA, Dept. Econometría, Estadística y Economía Española, Facultad de Economía y Empresa
AQR-IREA, Avenida Diagonal, 690, 08034 Barcelona.
Email: fabio.manca@ub.edu, tel: +34 934035886

Abstract: With this paper we build a two-region model where both innovation and imitation are performed. In particular imitation takes the form of technological spillovers that lagging regions may exploit given certain human capital conditions. We show how the high skill content of each region's workforce (rather than the average human capital stock) is crucial to determine convergence towards the income level of the leader region and to exploit the technological spillovers coming from the frontier. The same applies to bureaucratic/institutional quality which are conductive to higher growth in the long run. We test successfully our theoretical result over Spanish regions for the period between 1960 and 1997. We exploit system GMM estimators which allow us to correctly deal with endogeneity problems and small sample bias.
-Very very preliminary, do not quote.

Key words: Human Capital, Growth, Catch-Up.

.

JEL codes: O38, O33.

.

1 Introduction

It is usually argued how differences in the economic development of countries and regions depend on the differences in productivity levels. With this argument, nonethless, we are not giving any particular insight on how regions which are dramatically lagging behing in GDP per capita levels may actually improve on their economic situation w.r.t. the developed regions.

The argument of technology differences is usually accompained by the statement that human capital should be considered as one of the main factors boosting economic progress and growth both from a national and a regional view point. Nonetheless, recently, some doubts on the positive impact of human capital on economic growth arised. As pointed out by de la Fuente and Doménech (2006) from in a cross-country perspective. Many recent papers and empirical investigations found weak correlation between education variables and economic growth.

Why is that? We pursue the idea that the composition of human capital (the ratio of skilled over unskilled workers) rather than the average value of the stock, influences the processes of technology adoption and invention and, at the end of the day, drives economic growth and convergence in income levels.

Human capital, skills and institutional quality are the economic fundamentals that shape the form by which technology evolves within an economy. Depending on these economic fundamentals technological progress may take the form of either innovation or imitation and adoption. This, on the other hand, shapes and defines the growth possibilities of each region.

At early stages of development least developed regions may take advantage of their backwardness by imitating technologies discovered at the frontier. The process of technology adoption is not immediate however and it crucually depends on the recipient country's ability to implement these new technologies.

In our paper we assume that differences in human capital composition play a fundamental role in the speed by which lagging regions are able to exploit technological spillovers coming from close but more technologically advanced regions. By "human capital composition", as pointed out before, we refer to the region specific ratio of skilled over unskilled workers. We assume that it is the "skilled" fraction of the workforce to matter in the process of technology growth rather than the average human capital stock of an economy or region.

Other explanations and alternative theories can be recently found in the empirical and theoretical literature pointing to the negative role that higher education would have in the process of catch-up across countries and regions.[1] We

[1] A related paper on regional economic growth which embraces the point of view that primary education only is leading to catch-up of the least developed regions is that of Diliberto (2006) for the Italian case.

believe these theories to be counter-intuitive and probably related to spurious econometric results when not fully dealing with endogeneity issues related to the treatment of human capital in catch-up regressions.

From a theoretical point of view their argument is that technology imitation/adoption is not a costly activity (not even a skill-demanding one) so that imitation can be better performed by unskilled workers. However, there exist a good deal of empirical evidence (see for instance Teece (1977), Mansfield, Schwartz and Wagner (1981) or Behnabib and Spiegel (2005)) which is pointing to the "skill-costliness" of imitation and adoption of technologies. To put it in other words, we believe that technology adoption and imitation, since relying on reverse engineering activities or other forms of technical adoption, will be faster and stronger the higher is the technical and scientific content of the workforce in the recipient (follower) economy. "Unpacking" a technology in order to copy it or to imitate it is a skill-demanding acitivity which will be clearly better performed by specialized and trained workforce than by a relatively less educated one.

Ceteris paribus, if two technologically follower regions differ in their human capital skills, the economy with the higher number of engineers will be able to perfom better, more and faster the reverse engineering needed to adopt technologies discovered at the frontier and then it will eventually catch-up faster with the frontier. China is a clear example of a developing country heavily relying on technology imitation which is lately trying to increase the technical and educational content of its workforce so as to exploit the benefits from imitation and adoption possibilities.

With this paper we try to give some insights on these issues by analyzing the growth dynamics of two regions (region 1 and region 2) which differ in their development stage, composition of human capital, institutional quality and relative costs of innovation and imitation. We do so by merging some of the relevant features of the model by Helpman (1993) with those of the growth model by Barro and Sala-i-Martin (1997) and with the analysis of the impact of differences in human capital composition proposed by Vandenbussche, Aghion and Meghir (2004) on the process of technology innovation and adoption.

The remainder of the paper is as follows. In section 2 we give the basic setup of the model focusing on the main variables which will be analyzed throughout the paper. In section 3 we depict the behaviour of region 1 (the leader) and set the conditions by which innovation is performed at the frontier. In section 4, instead, we will describe region 2 (the follower) and the setup for imitation by focusing particularly on the costliness of imitation and adoption of technologies discovered at the frontier and on the impact of human capital composition and differences in institutional quality. Section 5 will be devoted to the study of the steady state growth and to the analysis of the transitional dynamics which leads the follower to theoretically converge towards the leader. Section

6, instead, shows our main theoretical results by analyzing the reaction of the follower economy to changes in the main variables of the model. We will analyze how these changes affect the decision of whether to perform imitation (and its optimality) rather than innovation and the effects on the long-run technological distance between the two regions. In section 7 we test empirically the main results of the theoretical model for Spanish regions for the period in between 1960 and 1997 both for regions and provinces. Due to the peculiarity of the data used, that is educational attainment levels and GDP gaps, we choose to estimate the underlying relations by making use of the system GMM estimators which allow us to build internal instrumental sets and to address many of the problems facing dynamic panel models. Section 8 concludes.

2 Setup of the model

Our model focuses on the dynamics linking the rich and technologically advanced regions to those persistently lagging behind. The theoretical analysis we propose, therefore, aims at examining how technology flows from the technological core of a nation, represented by its technologically developed regions and areas, to the less developed ones and how these spillovers change the economic prospects for these regions.

In particular we will be looking at the role that regional differences in human capital composition may play in these dynamics. For simplicity of exposition we will be assuming throughout the paper that only two regions exist and that these represent the technological leaders and followers. The two regions, denoted by i=1,2, represent respectively the technologically advanced regions and those, which instead are lagging behind.

The output in the representative region is expressed by means of a Spence (1976)/Dixit and Stiglitz (1977) production function as follows:

$$Y_i = A_i(L_{yi})^{1-\alpha} \sum_{j=1}^{N_i} (X_{ij})^{\alpha} \tag{1}$$

where $0 < \alpha < 1$, Y_i is output and X_{ji} is the quantity of the *jth* nondurable intermediate good used in the production by region i. N_i is the number of types of intermediates available in region i. As in Barro and Sala-i-Martin (1997) we use the variable N_i to proxy for the technological level of region i. The technology shown in eq. (1) can be accessed by all agents in region i and production occurs under competitive conditions. L_{yi} is instead the labor force employed in the production of output Y_i [2].

[2] Trade is assumed to be balanced between the two regions such that the domestic output is equal to the total of domestic expenditures which go for consumption of goods, C_i, production of intermediates, X_{ji}, and R&D aimed at discovering new blueprints and varieties of intermediates.

A_i represents institutional quality of regional governments. This variable captures the quality of the administration of local powers at regional level. This is particularly important within a nation like Spain which delegates many of its central powers to its *Comunidades Autonomas* which have large powers in budgetary and economic matters. It also captures all other unobservable differences across regions that are not explicitly modeled such as infrastructures and so on. In our empirical investigation we will proxy A_i by the overall economic environment within which each region and province is found by making use of an index of social capital[3]. We assume that region 1 owns more developed institutions than region 2 as follows:

$$A_1 > A_2 \tag{2}$$

The intuition is that regions with better institutional quality are also those which *ceteris paribus* experience higher levels of GDP per capita.

2.1 Regional differences in Human capital composition

We assume labor in the 2 regions to be heterogeneous in skills and human capital levels. In both regions a fraction of 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 which will be employed in the R&D activities of region 1and 2. The following general condition is hence satisfied:

$$L_i = L_{yi} + L_{ri} \tag{3}$$

where L_i is the total workforce which we normalize to 1. L_{yi} and L_{ri} represent respectively the low and high skilled shares of total workforce for region i. Noticeably, region 1 and region 2 differ in the composition of their human capital stocks. Region 1, consistently with empirical evidence, is populated by a relatively large share of high skilled workers (over its total population). This assumption tries to capture the evidence of higher schooling levels in developed regions than in developing ones. Our empirical investigation for spanish regions confirms this assumption with "Madrid" being the technological and human capital leader. Conversely, region 2, is largely populated by low skilled workers and only a relatively small fraction of its total workforce is highly skilled.

This condition can be restated more formally as follows:

$$L_{r1} > L_{r2} \tag{4}$$

[3]Social capital is defined as the degree of those" *relationships that evolve in the economic sphere, particularly in employment, financial or investment markets, in which long-lasting relationships exist in contexts of uncertainty and strategic interdependence*".

and, conversely

$$L_{y1} < L_{y2} \tag{5}$$

or

$$\frac{L_{r1}}{L_{y1}} > \frac{L_{r2}}{L_{y2}} \tag{6}$$

3 Innovation

The basic setting we use in order to model innovation combines various features of the formalizations of Barro and Sala-i-Martin (1997), Romer (1990) and Helpman (1993). In principle, a region can increase its technology stock (the pool of available intermediates for production N) either by inventing a new blueprint or by imitating or adopting an existing one which is known in the other region. In practice, however, we will be assuming that region 1 is initially the only innovator and that region 2 benefits from the discoveries made at the relative technological frontier by means of regional technological spillovers.

Hence, we assume region 1 to be the technological leader. This is implied by the following:

$$N_1(0) > N_2(0) \tag{7}$$

where the pool of blueprints (or intermediates) that are known in region 1 is strictly higher than that in the technological follower region 2[4]. The relative technological proximity between region 2 and region 1 is expressed by the following ratio:

$$0 < \frac{N_2}{N_1} < 1 \tag{8}$$

Throughout the paper we will be using the measure in eq.(8) to define the relative *development stage* of region 2 w.r.t. the most advanced technological area or region.

One of the crucial assumptions of our formalization is that innovation is a costly activity and, on the other hand, that technology spillovers do not happen spontaneously but crucially depend on the characteristics of the recipient regions, that is, on their particular human capital composition and skill levels.

Innovating, therefore, implies a unitary cost η_i to be performed. This represents the income outlay that a region incurs to produce one new blueprint or intermediate to be used in the production of the final good Y_i.

[4] This is to say that there are no intermediates known in 2 that are unknown in 1 such that region 1 never has the reason to imitate region 2.

Instead of assuming a fixed cost for innovation as in Barro and Sala-i-Martin (1997) we assume, somehow more realistically, that the marginal cost of increasing the technology stock of a region is a negative function of the fraction of population endowed with high skills. This is like saying that the relative easiness of producing a unit of innovation increases with the fraction of highly talented/educated researchers which are employed in the R&D sector. Our assumption is similar to that of Aghion and Howitt (2005), Behnabib and Spiegel (2005) or Grossman and Helpman (1981) who show how the human capital composition of the workforce, and not the average quality of human capital, is a crucial determinant of the amount of innovation that an economy may produce. Hence we assume the following cost function for innovation:

$$\eta_i = \psi(L_{ri})^{-1} \tag{9}$$

where, as pointed out before, η_i represents the cost of coming up with a new blueprint and L_{ri} is instead the share of high skilled workers employed in the R&D sector producing new knowledge.[5]

Notice that eq. (9) with eq. (4) imply the following:

$$\eta_2 \geq \eta_1 \tag{10}$$

The cost of producing a unit of innovation in region 1 is lower than in region 2 due to the higher share of high skilled workers employed in region 1 w.r.t. those employed in region 2. The different composition of human capital stocks in the two regions shapes their relative innovative possibilities. The region endowed with the higher fraction of high skilled labor ends up being relatively more efficient in producing innovation due to the more educated and talented researchers employed in R&D.

Notice that this result is somehow similar to that of the theoretical model of Vandenbussche, Aghion and Meghir (2004) where innovation is better performed at the frontier than by followers. Crucially, however, we will show how our setting, even if it conforms with this result, it does not also need to imply the puzzling assumption that unskilled workers are better suited for imitation activities (reverse engineering for example) than more skilled workers as in Vandenbussche, Aghion and Meghir (2004).

For simplicity of exposition we assume for now that the shares of high and low skilled workers in the two economies remain constant such that eq. (10) holds over time[6].

[5] We assume here, for simplicity, that ψ is a linear function. This may not be the case however and more complexity may be added to the model in assuming a non linear relation between the cost of innovation and the share of skilled workers employed in R&D. We believe results will not change qualitatively.

[6] Results would be the same if we allowed human capital composition to slowly change over time as in reality may happen. Mathematical tractability would be, however, more demanding not adding much to the results.

Let us now assume a new intermediate is introduced (invented) in region 1. The innovator initially retains monopoly power over the use of this good for production[7]. Since the intermediate j is priced in region 1 at P_{1j} the flow of monopoly profit to the inventor is given by:

$$\pi_{1j} = (P_{1j} - 1)X_{1j} \tag{11}$$

where the 1 inside the brackets represents the marginal cost of producing the intermediate X_{ij}. The marginal product of the jth intermediate is instead given by:

$$\partial Y_1/\partial X_{1j} = A_1 \alpha L_{y1}^{1-\alpha}(X_{1j})^{\alpha-1} \tag{12}$$

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

$$X_{1j} = L_{y1}(A_1\alpha/P_{1j})^{1/1-\alpha} \tag{13}$$

By substituting eq.(13) into eq.(11) we get the monopoly price, which is the same for all types of intermediates:

$$P_{1j} = P_1 = 1/\alpha > 1 \tag{14}$$

This in turns implies that the total quantity of the jth intermediate that region i will be producing amounts to the following:

$$X_{1j} = X_1 = L_{y1}(A_1)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)} \tag{15}$$

From this we finally get region's 1 total output by substituting eq.(15) into eq.(1) which gives:

$$Y_1 = (A_1)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)}L_{y1}N_1 \tag{16}$$

Hence, total output is going to be a positive function of regions specific institutional/bureaucratic quality. Also, holding constant regions specific institutional quality, output per capita is going to increase as the technology level N, the number of intermediates available for production, increases[8].

By susbsituting eq.(14) and eq.(15) into eq.(11) one can get the flow of monopoly profit from sales to the owner of the rights of intermediate j as follows:

$$\pi_{1j} = \pi_1 = (1-\alpha)L_{y1}(A_1)^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)} \tag{17}$$

[7] As pointed out by Barro and Sala-i-Martin (1997), it is however simple to allow the good to become competitive with an exogenous probability p per unit of time.

[8] It is difficult to see from eq. (16) the partial effect of an increase of respectively the skilled or of the unskilled fraction of workforce on total output since N is a function of human capital composition. We will show in the next sections how it is the increase of the high skill share of the workforce to be growth enhancing while an increase in the fraction of population endowed with low skills will result to be growth detrimental.

As argued by Barro and Sala-i-Martin (1997) the present value of profits for the jth innovator is simply π_{1j}/r_1, where r_1 is the rate of return in region 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 must equal the constant cost of invention η_1 at each point in time. Hence, rearrangement of the free-entry condition implies the following rate of return for region 1:

$$r_1 = (L_{y1}/\eta_1)\left(\frac{1-\alpha}{\alpha}\right)(A_1)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)} = \pi_1/\eta_1 \tag{18}$$

where the rate of return r_1 is the ratio of π_1, the flow of monopoly profit given in eq.(17), to the cost η_1 of obtaining this profit flow.

We assume that consumers maximize utility over infinite horizons through a standard Ramsey type utility function as follows:

$$U_1 = \int_0^\infty e^{-\rho t}\left[(C^{1-\theta}-1)/(1-\theta)\right]dt \tag{19}$$

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[9]. If we maximize the utility function subject to a standard budget constraint we obtain the usual expression for the consumption growth rate:

$$\dot{C}_1/C_1 = (1/\theta)(r_1 - \rho) \tag{20}$$

where the growth rate of C_1 is constant due to the constancy of r_1 as in eq.(18). Hence, the growth rate of the economy in full equilibrium is given by :

$$\gamma_1 = (1/\theta)(\pi_1/\eta_1 - \rho) = (1/\theta)\left[(1-\alpha)L_{y1}(A_1)^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}\eta_1^{-1} - \rho\right] \tag{21}$$

where the parameters of the model are such that $\pi_1/\eta_1 \geq \rho$ ensures positive growth.

4 Imitation/adoption in the follower region

4.1 Technology spillovers

Technology spillovers from the technologically developed region to the follower do not take place spontaneously. Imitation and adaptation of leading-edge technologies imply a cost for the follower. The costliness of imitation is widely observed and acknowledged in theoretical and empirical literature. Maskus, Saggi and Puttitanun (2004), Mansfield, Schwartz and Wagner (1981), Coe and Helpman (1995) or Behnabib and Spiegel (2005) point out how the cost of both the

[9] This implies the intertemporal elasticity of subsitution being equal to $1/\theta$.

adaptation and imitation of technologies discovered at the frontier (or in other technological sectors) is usually positive but relatively lower than the cost of innovation.

As argued by Maskus (2000), imitation usually takes the form of adaptations of existing technologies to new markets[10]. Mansfield, Schwartz and Wagner (1981) point out for instance how, over 48 different products in chemical, drug, electronics and machinery U.S. industries, the costs of imitation lied between 40% and 90% of the costs of innovation. On the same line the empirical results of Teece (1977) who estimated the cost of technology transfer across regions to be equal, on average, to 19% of total project expenditure. Nelson and Phelps (1966) argue, moreover, how imitation and adoption imply an investment in human capital while Abramovitz (1986) emphasises the role played by social and institutional resources in order for follower regions to adopt technologies discovered at the frontier.

We build on previous theoretical literature and express the cost function for imitation by the following:

$$\nu_2 = \eta_2 \left(\frac{N_2}{N_1} \right)^{\sigma} \tag{22}$$

where ν_2, representing the cost of imitation in region 2, is assumed to be a function of η_2, and of N_2/N_1 the proximity to the frontier.

Few things are worth noticing. First of all, in the fashion of Connolly and Valderrama (2005) and Barro and Sala-i-Martin (1997) we assume the cost of imitation to be an increasing function of the proximity of the imitator w.r.t. the technological frontier. The rationale goes as follows. When it exists a large pool of innovations (blueprints) from which an imitator can copy, the cost of imitation tends to be low. This happens when the ratio N_2/N_1 is small and the follower is relatively far from the frontier. When, the pool of blueprints available for imitation shrinks, due to a higher proximity of the follower w.r.t. the leader, the costs of imitation rise due to the fact that the remaining blueprints may be those more difficult to be imitated (or to be adjusted to production processes in region 2). This happens when the ratio N_2/N_1 gets close to 1. Hence, similarly to Barro and Sala-i-Martin (1997) when blueprints available for imitation in the follower region are exahusted, the cost of imitation equals the cost of innovation, η_2, since imitation cannot be performed anymore and possible technological spillovers are completely exahusted.

The parameter σ aims at capturing the relative strength of the technological spillovers coming from the frontier when geographical distances are allowed for. In other words, we expect that the more distant the leader region is from the

[10] In an ongoing research we show how Spain is the fifth country in the EU for the degree and intensity of adoption and diffusion of new products and processes. These results are obtained by the exploitation of the third vawe of the Community Innovation Survey (CIS3).

follower, the weaker the effect of the discoveries made at the frontier will be on the follower. Technological specialization usually creates clusters of regions with positive technological externalities. [11]However, as soon as we increase the distance across regions the technological links tend to fade and economic and technological activities in leader regions to become less important w.r.t. geographically distant regions. More formally we assume $\sigma > 1$ such that the geographical distance matters in the possibility of exploiting technological spillovers[12].

However, it is not only the relative proximity of the follower to the technological frontier to be important in defining the cost function for imitation, however. We innovate on Barro and Sala-i-Martin (1997) formalization, by assuming the cost of imitation to be decreasing in the share of high skilled workforce employed in imitation activities in the economy.

Noticeably, regarding the impact of the share of high skilled workers on the cost of imitation, our assumption is somehow alternative to the one of Vandenbussche, Aghion and Meghir (2004) in which a low skilled worforce is assumed to be better suited for imitation tasks than a more skilled one. In Vandenbussche, Aghion and Meghir (2004) an increase of the share of unskilled workforce (when region 2 performs imitation) results to be growth enhancing since the elasticity of unskilled labor is higher in imitation than in innovation[13]. We believe, instead, that imitation requires a consistent amount of skills at any development stage.

We rely on the economic intuition of Nelson and Phelps (1966) for which the speed of technology catch-up is a positive and increasing function of human capital levels. The higher the human capital of a lagging economy and the faster its technological catch-up. Nelson and Phelps (1966) argue how "*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*".

We insert into this same line of reasoning by arguing how reverse engineering, on which a considerable part of the imitation activities is based, is more likely to be performed by engineers rather than by low skilled workers. For this reason technology imitation is likely to rely on skilled workers while it is the physical

[11] Even if we formalize this aspect in the theoretical model, in this version of the paper we still do not take into account this dimension in the empirical part. Results of the theoretical model remains unchanged however if we drop the parameter σ.

[12] Keller (2001) estimated the max geographical distance for technology spillover to take place in 1,200 kilometers.

[13] The authors argue how "*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*".

production of the "replicas" used for production of the final good to be carried out by unskilled workers. Following this rationale, our formalization implies that the cost of imitation will be lower the higher the share of skilled workforce in region 2. More formally combining eq. (22) with eq. (9) we can restate the cost function for imitation as follows:

$$\nu_2 = \psi(L_{r2})^{-1} \left(\frac{N_2}{N_1}\right)^{\sigma} \tag{23}$$

Also, *ceteris paribus*, as we move closer to the technological frontier, the importance of higher education and technical skills of the workforce performing *imitation* and adoption becomes increasingly more important.

4.2 The follower region

Now that we have set the conditions for the cost function of imitation we can move to the behaviour of region 2. We assume that region 2 starts in a situation where the cost of innovation is strictly higher than the cost of imitation such that:

$$\eta_2 > \nu_2(0) \tag{24}$$

We assume that once a blueprint is discovered in region 1 it will be available for adoption by an agent in region 2. We assume that the adoption of the blueprint by the technological follower implies some sort of adjustment of the blueprint. The outcome of adoption results to be new intermediate good X_{2j} which will be similar to the initial one X_{1j} discovered in the leader region but "ready-to-use" for production in region 2. Similarly to what happens in region 1, the imitator in region 2 will retain monopoly power over the use of the imitated good for production.

The monopoly price in region 2 for the *jth* imitated good, similarly to eq.(14), will be given by

$$P_{2j} = P_2 = 1/\alpha \tag{25}$$

and also eq.(15) to eq.(17) will be the similar to those for region 1 as follows:

$$X_{2j} = X_2 = L_{y2} A_2^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} \tag{26}$$

$$Y_2 = A_2^{1/(1-\alpha)} \alpha^{2/(1-\alpha)} L_{y2} N_2 \tag{27}$$

$$\pi_{2j} = \pi_2 = (1-\alpha) L_{y2}(A_2) \alpha^{(1+\alpha)/(1-\alpha)} \tag{28}$$

The computation of the rate of return in region 2 is, instead, slightly more complex than that for region 1. This is because the cost of imitation is increasing over time being a positive function of the ratio N_2/N_1. For this reason we follow the simpler formalization proposed by Barro and Sala-i-Martin (1995)[14] by assuming that the follower region is far from the technological frontier and that the pool of available innovations to be imitated is large so that the rate of return will be nearly constant and given by the following:

$$r_2 = (L_{y2}/\nu_2)\left(\frac{1-\alpha}{\alpha}\right)(A_2)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)} \tag{29}$$

Interestingly, a gap in rate of returns arises between region 1 and region 2 since the cost of imitation in region 2 is initially lower if compared to the cost of innovation in region 1. This gap is such that $r_2 > r_1$ during the transitional dynamics[15].

As in region 1, consumers in region 2 are assumed to maximize the same Ramsey-type utility function as in eq.(19). This leads to the following expression for the growth rate of consumption:

$$\dot{C}_2/C_2 = (1/\theta)(r_2 - \rho) \tag{30}$$

which ultimately gives the growth rate for region 2 as a function of model parameters:

$$\gamma_2 = (1/\theta)(\pi_2/\nu_2 - \rho) = (1/\theta)\left[(1-\alpha)L_{y2}(A_2)^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}\nu_2^{-1} - \rho\right] \tag{31}$$

5 Steady state and growth dynamics

In our study we are mainly concerned with the growth dynamics of both region 1 and region 2 when imitation and innovation are costly activities and differences in human capital composition exist between the two regions. However, in order to be more specific about the dynamic behaviour of the economies it is convenient to start with the analysis of steady state growth and then to move to the analysis of the transitional dynamics.

In steady state the two economies are expected to grow at the rate of expansion of the technology frontier, that is at γ_1. By definition, therefore, in steady state N_2 grows at the same rate as N_1 so that ν_2 remains constant in accordance

[14] A slightly more complex formalization is given in Barro and Sala-i-Martin (1997) where the rate of return for country 2 is expressed by $r_2 = \pi_2/\nu_2 + \dot{\nu}_2/\nu_2$ where r_2 includes the capital gain term $\dot{\nu}_2/\nu_2$ which adds to the dividend rate π_2/ν_2. We refer the interested reader to Barro and Sala-i-Martin (1997), p.8.

[15] For now it is convenient to notice simply that under the general assumptions given from eq.(4) to eq. (9), for $N_2/N_1 < (N_2/N_1)^* < 1$ it will always hold that $r_2 > r_1$. The asterisk superscript represents the technology proximity of the follower w.r.t. leader in steady state. We will discuss this situation in the next section.

with eq. (22). Also, C_1 grows at the same rate as C_2 which corresponds to γ_1 in the long run.

As argued by Barro and Sala-i-Martin (1997), the process of technology diffusion will end up equalizing the rate of returns in the two regions. The steady state value of the rate of return expressed in eq. (29) for region 2 will be equal to that of the leader region 1 as follows:

$$r_2^* = r_1 = \pi_1/\eta_1 \tag{32}$$

where the asterisk superscript denotes values in steady state for region 2. Hence, since $r_2^* = r_1$, eq. (18) and eq.(29) imply:

$$\pi_2/\nu_2^* = \pi_1/\eta_1 \tag{33}$$

where ν_2^* represents the corrispective steady state value for the cost of imitation ν_2. By combining eq.(17) with eq.(28) we can express the steady state value for the cost of imitation as a function of the other variables of the model, leading to the following:

$$\nu_2^* = \eta_1(A_2/A_1)^{1/(1-\alpha)}(L_{y2}/L_{y1}) \tag{34}$$

Now, for any given value of $\nu_2(t) < \nu_2^*$ the follower region 2 will be found below its steady state. Due to the relative gap in rate of returns between the technology adoption activity performed by region 2 (which is highly profitable at initial stages of development) and the innovation performed by region 1, region 2 will be growing faster than region 1 during the transitional path[16].

One may think of this situtation as region 2 having a cost "*comparative advantage*" w.r.t. the leader which makes it able to grow relatively faster. Nonetheless, as region 2 converges towards the technological level of the leader (N_2/N_1 gets bigger) the cost of imitation in region 2 rises up to a point where region 2 completely exahusts its "*growth comparative advantage*" and starts growing at the rate of the technological frontier. That is, γ_2 goes from being initially higher than γ_1 to a situtation where $\gamma_2^* = \gamma_1$ in steady state[17]. More formally we have the followings:

$$\nu_2(t) = \nu_2^* \Longleftrightarrow \gamma_2^* = \gamma_1 \tag{35}$$

while, during the transition dynamics it will be that

$$\nu_2(t) < \nu_2^* \Longleftrightarrow \gamma_2 > \gamma_1 \tag{36}$$

[16] This is to say that during the transitional path the cost of imitation in region 2 is lower than the cost of innovation in region 1 up to the point where $\nu_2(t) = \nu_2^*$ and where the rate of returns of imitation in region 2 and innovation in region 1 equalize.

[17] This also implies a technology gap between region 1 and region 2 equal to $(N_2/N_1)^*$.

6 Human capital composition

Up to now we have been analyzing the situation for which region 2 grows faster than region 1 by profitably imitating the technologies discovered in the leader region. We now recall two general assumptions we made for region 2 in previous sections which may come at hand now.

Firstly we assumed that the cost of imitation in region 2, $\nu_2(0)$, is lower than the cost of innovation in region 1, η_1, (condition for which region 2 theoretically converges to region 1).

Secondly we assumed that in region 2 imitation or adoption is cheaper than innovation, that is, the cost of imitation $\nu_2(0)$ is lower than the corrispective cost of innovation η_2 (condition for which imitation is performed rather than innovation)[18]. The choice of imitating rather than innovating is therefore based on the positive gap between $\nu_2(t)$ and η_2. More formally we have been assuming the following:

$$\nu_2(t) < \eta_1 < \eta_2 \tag{37}$$

Now, in order to get useful policy making insights we have to switch the perspective of the analysis from the transitional dynamics path to the analysis of the relations in the long run.

The crucial question is the following: is imitation an optimal activity in the *long run* for the follower regardless of its development stage, human capital composition and bureaucratic quality?

In particular, the relative composition of human capital (skilled over unskilled workers) and the level of institutional quality enter the cost function of imitation and innovation and therefore define the conditions for which imitation may (or may not) be optimal in the long run.

Hence, we are now interested in defining under what general conditions imitation, rather than innovation, results to be an optimal activity for the follower *in the long run*. This reduces to finding for which model parameter values the cost of imitation is lower than the cost of innovation in the long run, that is $\nu_2^* < \eta_2$.

Putting together eq.(37) with eq.(34) we can restate the following:

$$\nu_2^* < \eta_2 \Leftrightarrow (A_2/A_1)^{1/(1-\alpha)} L_{y2}/L_{y1} < \eta_2/\eta_1 \tag{38}$$

[18]Recall, also, that $\eta_2 > \eta_1$ strictly holds, that is, the cost of innovation in country 2 is strictly higher than the cost of innovation in country 1 due to the relative difference in human capital stocks composition across countries.

This yelds to the following, more general, condition for the relative human capital composition ratio between the two regions satisfying $\nu_2^* < \eta_2$:

$$\kappa > \xi \theta^{1/1-\alpha} \tag{39}$$

where we redefined the variables as follows[19]:

$$\kappa = \eta_2 / \eta_1 \tag{40}$$

$$\xi = (L_{y2}/L_{y1}) \tag{41}$$

$$\theta = A_2/A_1 \tag{42}$$

Crucial for our discussion is that, as long as the disequality in eq.(39) holds, the steady state cost of imitation for region 2 will be strictly less than the corrispective cost of imitation η_2 given the economic fundamentals in region 2. Hence, in that case, the follower will always choose to imitate. This condition is satisfied for relatively low values of the quality of human capital in the follower region w.r.t. the leader. We restate this condition more formally in the proposition below.

Proposition 1 *As long as differences in human capital skills between leader and follower are large the follower region always finds optimal to imitate in the long run. Improvements in the economic fundamentals of region 2 (both bureaucratic/institutional quality and human capital and skills) make imitation increasingly less attractive w.r.t. innovation for the follower region.*

The intuition behind this result is as follows. For large enough differences human capital composition and bureaucreatic quality between region 1 and region 2 the steady state cost of imitation in region 2 will be always lower than its corrispective cost of innovation, that is $\nu_2^* < \eta_2$. Hence when skills in the follower region are low enough imitation will result to be an *easier* and more profitable activity for the follower if compared to innovation.

Being more specific, as regards human capital composition, an increase in the share of the high skilled workforce in region 2 implies a reduction of the costs of imitation (as shown in eq. (23)) but also a reduction of the cost of producing potential innovation (as shown in eq.(9)).

It is evident, in our formalization, that an increase in the high skilled share of the total workforce results to be generally growth enhancing reagardless of the type of activity which is carried out by the region under consideration. This, as it will be clear, it is the main theoretical result on which we want to focus

[19] Notice that the new variables in eq.(39) are all expressed as the ratio of the follower's quantities over the leader's in order to make the analysis more readable.

and that it will be analyzed also from an empirical point of view in the next sections.

However, the impact of human capital over imitation and innovation activities is uneven. While an increase of L_{r2} implies a proportional decrease in the cost of producing innovation, its impact on the imitation cost depends on the actual proximity to the technological frontier, N_2/N_2 , that is on the follower's development stage as shown in eq.(23).

Ceteris paribus, increasing the high skilled content of the follower's workforce leads to an increase of the ratio ξ/κ. This implies, on the other hand that the disequality in eq. (39) is gradually less likely to hold for any given value of model parameters in the follower region. To put it in other words, imitation becomes less attractive in the long run when the economic fundamentals of the follower improve, namely when the share of high skill human capital in the follower increases.

Regarding to the institutional quality differences between region 1 and 2, as expected, they play a role in the definition of the conditions for which imitation rather than innovation results to be optimal in the long run. In particular we find how an increase in the quality of institutions in the South implies a minor attractiveness of imitation w.r.t innovation with the disequality in eq.(39) being less likely to hold for high values of A_2. Even if it is difficult to determine the causality between institutional improvements and economic development[20], it is clear how the two phenomena evolve on parallel paths and usually coexists[21].

Proposition 2 *The long-run technological proximity between region 1 and 2 depends on the relative differences in the composition of human capital, on differences in institutional and bureaucratic quality and on the geographical distance between the two regions which diminishes the strength of technological spillovers.*

This result can be seen clearer when we derive the expression for the steady state value of the technology gap $(N_2/N_1)^*$ between region 1 and 2. Combining eq.(22) with eq.(34) makes it possible to derive a unique value for N_2/N_1 which satisfies the steady state condition $\nu_2(t) = \nu_2^*$. This is given by the following:

$$(N_2/N_1)^* = \left[\xi\,(\theta)^{1/(1-\alpha)}\,/\kappa\right]^{1/\sigma} \tag{43}$$

[20] See Hall and Jones (1999) for an example of this analysis.

[21] As in Acemoglu, Aghion and Zilibotti (2006), it is here evident how some "poor institutional arrangements" may optimally arise at initial stages of development of a country (in our case the consideration holds at a regional level) but that these will be abandoned as a country catches up with the frontier.

Interestingly, the long run proximity of region 2 w.r.t. technological frontier is an increasing function of the institutional quality endowement of the follower, namely of θ. This can be seen by examination of eq.(34) and eq.(43). Better institutions in region 2 are associated with higher technology levels in the long run. Also, the larger the geographical distance across regions, the higher σ, and the lower will be the technological proximity in the long run.

More importantly for our discussion is that an increase in the fraction of population endowed with higher skills in region 2 leads to the achievement of a higher long-run technological proximity w.r.t. the leader region. It is therefore the high skill content of the total workforce to be crucial and conductive to higher growth and higher levels of output in the long run. We show the implications of our proposition in the graph below:

It is here assumed that $Lr_2^{'} < Lr_2^{''} < (Lr_2^{'''} = \tilde{L}r_2)$ where the tilde denotes the situation for which imitation is indifferent w.r.t. to innovation in region 2. Increasing the fraction of the workforce with high skills flattens the cost function for imitation in region 2. Technology spillovers are now easier to be received and technological growth in region 2 goes at a faster pace. Crucially, however, once $\nu_2^* = \eta_2$ region 2 becomes indifferent on whether performing imitation or innovation. Hence, when $Lr_2^{'''} = \tilde{L}r_2$ holds unique value for $(N_2/N_1)^*_{Lr'''}$ is found which represents the maximum proximity w.r.t. technological frontier attainable in imitation given the specific economic fundamentals of region 2.

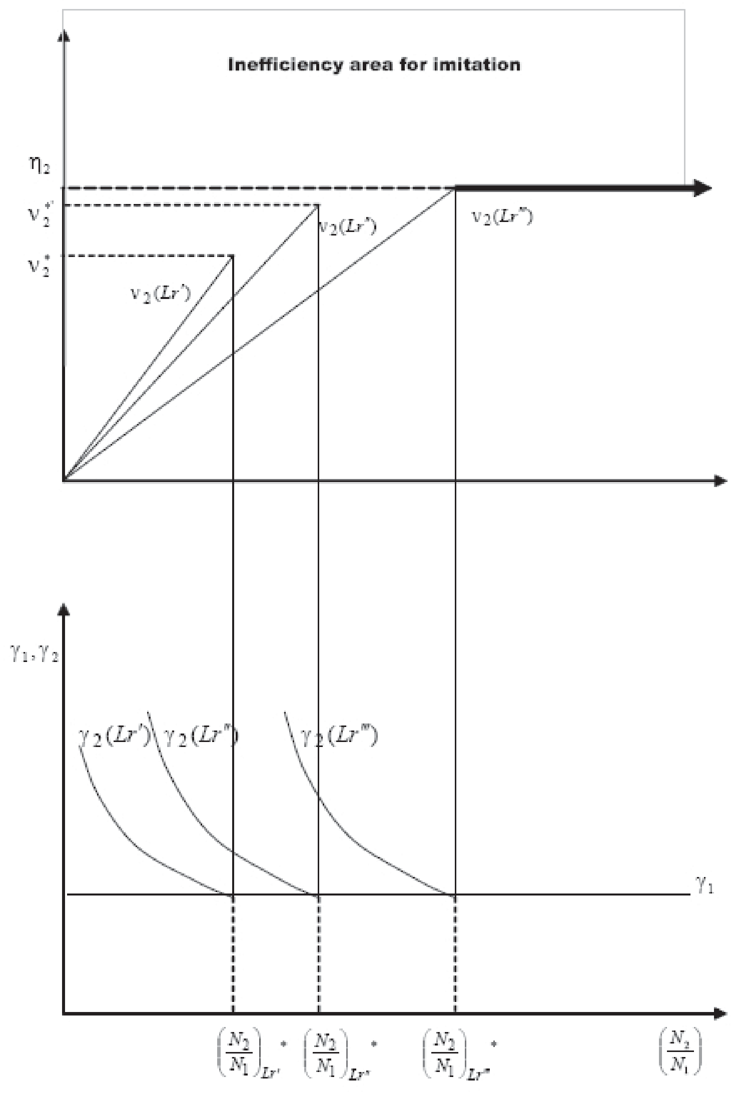
Corollary 3 *Given the follower's particular human capital composition, institutional quality and development stage an upper bound level for the skill content of human capital in region 2 is found such that the follower is indifferent on whether performing imitation or innovation;* $\tilde{L}r_2 \equiv (\xi/\kappa)^{1-\alpha} = \theta^{-1}$.

Proposition 4 *A rise in the fraction of population with a higher level of education is growth enhancing under plausible conditions. Conversely, a rise in the fraction of population with a lower degree of education is growth diminishing. The result applies in imitation or innovation for both region 1 and region 2 economies. The result holds as long as basic education is positive.*

This result can be seen by the inspection of the growth rate in eq. (21) for the leader or from its corrispective in eq.(31) for the follower. Everything else being equal, the growth rate of the economy is a function of the level of educated (skilled) over uneducated (unskilled) workers in the economy. Taking the partial derivative of the growth rate w.r.t. L_{ri} and imposing this to be greater than zero yelds to the following:

$$\frac{\partial \gamma_i}{\partial L_{ri}} = (1/\theta)\left[(1-\alpha)(A_i)^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}\eta_i^{-1} - \rho\right][1-2L_{ri}] \qquad (44)$$

Figure 1: Transitional dynamics



Due to the assumptions made on the model parameters in order to ensure positive growth, the term $(1/\theta)\left[(1-\alpha)(A_1)^{1/(1-\alpha)}\alpha^{(1+\alpha)/(1-\alpha)}\eta_1^{-1}-\rho\right]$ will be always greater than zero. This leads to the following:

$$\frac{\partial \gamma_i}{\partial L_{ri}} > 0 \Leftrightarrow L_{ri} < 1/2 \tag{45}$$

The derivative in eq.(44) shows how an increase in the skilled fraction of workforce is growth enhancing for plausible values of L_{ri}, that is for values of L_{ri} below the half of the total population. Instead, the opposite is true for the unskilled population. That is, when L_{yi} is above 1/2 an increase in the fraction of population with a lower degree (which decreases the fraction of those with a higher one) will be growth detrimental.[22]

This result points also to the importance that basic education has on growth. This is to say that the positive marginal impact of higher education on technology convergence holds as long as basic education is considerably spread (in levels) in the follower economy (in our case it must be that $L_{yi} > 1/2$). Once this condition is satisfied, that is that basic education is guaranteed to a high fraciton of the population, then an additional increase in the basic education can be growth detrimental if compared to the positive effect that, instead, would have an increase in higher education.

Proposition 5 *An optimal growth path for the follower can be found given its economic fundamentals. This path implies a switch from imitation to innovation at high development stages. Improvements in institutional quality, θ, and increases in the high skilled share of follower workforce are growth enhancing and may theoretically lead to leapfrogging of region 2 w.r.t. region 1.*

From the analysis of the propositions above we know that it is the upper bound level for human capital skills that makes region 2 indifferent on whether imitate or innovate is $\tilde{L}r_2$. This upper bound defines the higher long run technology proximity that region 2 can achieve w.r.t. region 1 in imitation, that is, $(\tilde{N}_2/\tilde{N}_1)^*$.

A higher proximity w.r.t. the technological frontier, however, can be achieved by switching to innovation once $(\tilde{N}_2/\tilde{N}_1)^*$ has been reached. Crucially, if region 2 starts innovating above $(\tilde{N}_2/\tilde{N}_1)^*$ the new steady state value for technology proximity of region 2 w.r.t. region 1 will be still an increasing function of the high-skill content of its human capital.

[22] In both cases the relation between the increase in the share of high skilled human capital and the growth rate of the economy is not linear and it encounters diminishing returns pointing to possible duplication effects as argued by Romer (1990).

Convergence in technological levels is therefore conditional in the sense that it depends on the economic fundamentals of the two economies. Let us express the attainable income ratio between region 2 and region 1 in the long run by combining eq.(27) with eq.(16) and eq.(43). This is as follows:

$$(Y_2/Y_1)^* = \left[\theta^{1/(1-\alpha)} \left(L_{y2}/L_{y1}\right) \left(\hat{N}_2/\hat{N}_1\right)^*\right] \tag{46}$$

However, the income ratio between the two economies will not remain constant due to the relative differences between the economic fundamentals of region 2 w.r.t. those of region 1 which is still more efficient in producing innovation. Hence, increasing the fraction of workforce with higher skill is not sufficient to achieve absolute convergence with the leader. In fact, as expected, unless region 2 improves on its economic fundamentals it will be "trapped" in a high development stage (depending on its relative composition of human capital and institutional quality). This scenario captures the situation of those regions at the frontier which are developed but still fail in reaching the exact income standard of the leaders due to small but persistent differences in R&D or institutional quality.

As region 2 improves on its economic fundamentals it gets to a higher steady state technological proximity to the leader. Absolute convergence may be achieved, therefore, by rising the high skilled fraction of total workforce or the overall institutional quality of the economy. In fact, from eq.(9), eq.(40) and the corrispective for economy 2 of eq.(44) it may be seen how an increase in L_{r2} will imply a decrease in κ, the ratio η_2/η_1 which represents the inverse of the efficiency of the R&D sectors in the two economies. Similarly, also an increase of institutional quality of region 2 ends up leading to an increase in the ratio $(Y_2/Y_1)^*$ by rising the parameter θ. To conclude, leapfrogging of region 2 w.r.t. region 1 is also possible when region 1 becomes intrinsically inferior w.r.t. region 2 in its economic fundamentals, institutional quality and human capital. When this happens the analysis is the same but reversed with region 1 being the follower.

7 Empirical results

7.1 Data

This part of the paper will be devoted to the empirical test of the dynamics underlined in the theoretical model presented before. Our analysis will be focusing on the 17 Comunidades Autonomas españolas [23] as well as on 50 spanish provinces. The time span selected ranges from 1960 to 1995 for the analysis on the regions and from 1965 to 1997 for the analysis of the province case. The

[23] Our sample is Andalucía, Aragón, Asturias, Baleares, Canarias, Cantabria, Castilla y León, Castilla la Mancha, Cataluña, Comunidad Valenciana, Extremadura, Galicia, Madrid, Murcia, Navarra and Pais Vasco.

two cases, the regional and the province analysis, differ in the databases that are going to be employed for both the GDP values and human capital variables.

If, on one hand, this is somehow a natural constraint we have to face due to the human capital data availability at the spanish regional level (the data that we use for the regional case are not available from the same source also at the regional level), on the other hand, it allows us to exploit two different databases and, therefore, to infer something on the overall robustness of the results when the analysis is not only carried out at two different aggregation levels but also with two different datasources.

The regional analysis exploits a 5-year dynamic panel model while the case of the provinces, due to the higher frequency of the data, the dynamic panel will be of 4-years span. The GDP series used in the regional case is expressed in per capita terms and is made available by the Fundación BBVA. The data used as a proxy for regional differences in human capital stocks are those proposed by de la Fuente, Domenéch and Jimeno (2006). These data conveniently allow us to disaggregate the population of age 25 and over by categories of educational attainment. To be more specific we focus on the following educational attainment categories: (*HK1*) primary - *primaria, graduado escolar* whose duration is 5 years, (*HK21*) lower secondary - *EGB, Bachiller elemental, ESO* whose duration is 3 years, (*HK22*) upper secondary - *Bachillerato, COU, FP I and FP II* whose duration is 4 years, (*HK31*) higher education, first level - *Diplomatura, Peritaje* whose duration is 2 years and finally (*HK32*) higher education, second level - *Licenciatura* whose duration is 3 years.

The data for the GDP at the province level comes also from the BBVA Foundation while the data for the human capital at the same disaggregation level comes from the "Human capital series" provided by the IVIE in collaboration with Bancaja.[24]

The human capital series at the province level refers to the following nominal categories: *(HK1)* "analfabetos" or with no education, *(HK2)* "primaria"or primary schooling, *(HK3)* "medios" or secondary schooling, *(HK4)* "antes-superiores" or vocational training and *(HK5)* "superiores" or higher education. The data are here expressed in thousand of people employed (active population) for each branch of educational attainment.

If we compare the two human capital databases we will notice how the category *(HK3)* and *(HK4)* of the human capital series for the provinces refer to those educational attainment levels ranging from the secondary compulsory education (for the *HK3*) to the pre-university degrees. These two categories, therefore, correspond partly to those *(HK21)*, *(HK22)* and *(HK31)* of the regional classification given in de la Fuente, Domenéch and Jimeno (2006) database. *HK5*, instead, corresponds to the higher skill margin of the workforce

[24] See: http://ivie.es/banco/capital.php?idioma=EN for more details

in the province database while, in the regional case its corrispective is named *HK32*.

Our study is also concerned with the role played by institutional quality when this interacts with human capital levels in defining the growth path of the economies.

Data proxying for the institutional quality at the regional and provinces level is very hard to find. To the best of our knowledge, the best approximation for the spanish case are the data for Social Capital provided by the IVIE in collaboration with the BBVA Foundation. These data focus on the role of cooperation and trust in achieving collective or economic results and it may be an adequate proxy at the regional and province level of the quality and correct functioning of their institutions. In particular, the approach followed in the construction of the data for spanish social capital focused on the "*social relationships that evolve in the economic sphere, particularly in employment, financial or investment markets, in which long-lasting relationships exist in contexts of uncertainty and strategic interdependence*".[25]

The data for social capital matches our sample at the regional and province level for the period in between 1981 and 1997. This is a shorter time span if compared to the data we have available on human capital and GDP.

Due to the already small number of observations for the regional case[26] the use of the social capital data in the context of the regional analysis has been therefore dropped. Its use, instead, for the provinces case reduce the sample from 400 observations to 250 observations[27] so we decided to propose the empirical analysis of the impact of human capital composition either with and without controlling for institutional quality differences at the province level.

7.2 Methodology

The relation between education and economic growth is likely to be heavily affected by severe problems of endogeneity. In other words, the covariates may not be orthogonal to the error process and the resulting estimates may not be consitent. Usually in a cross-section context, this problem is solved by using instrumental variables techniques (IV) which rely on instrumental sets which are assumed not to be correlated to the error process but at the same time highly correlated to the suspected endogenous variables. Unfortunately, economists usually face huge problems in finding such instrumental sets.

Within the dynamic panel settings this problem is usually adressed by making use of first-difference GMM estimators such as those proposed by Arellano

[25] See IVIE, http://ivie.es/banco/ksocial.php?idioma=EN.
[26] Without the use of social capital we have 119 observations.
[27] In the case of the system GMM estimation.

and Bond (1991) or Arellano-Bover(1995)/Blundell-Bond (1998). These estimators allow 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).

In our particular analysis, moreover, we face another problem related to the educational variables we are going to exploit. As argued by Castelló (2006) educational variables are usually highly persistent over time. It is well known that system GMM estimators for dynamic panel data models generally perform better than standard first-difference estimators when variables are persistent. Blundell and Bond (1998) show that when the considered variables are close to random walk processes then the difference GMM estimators behave poorly because past levels of these variables convey little information about future realizations.

To be slightly more specific, as pointed out by Roodman (2006), the Arellano and Bover (1995) and Blundell and Bond (1998) estimators augment the standard Arellano and Bond (1991) procedure by assuming that first differences of instrumenting variables are uncorrelated with the fixed effects and by allowing the introduction of more instruments which consistently improve the efficiency of the estimator. Formally the system GMM estimator assumes the following:

$$E\left[\Delta W_{i,t-1}\varepsilon_{i,t}\right]=E\left[\Delta W_{i,t-1}\mu_i\right]+E\left[W_{i,t-1}\upsilon_{i,t}\right]-E\left[W_{i,t-2}\upsilon_{i,t}\right]=0+0-0 \quad (47)$$

where μ_i are the fixed effects and $\upsilon_{i,t}$ are the idiosyncratic shocks. $W_{i,t}$ represents instead the endogenous regressors. If the condition above is satisfied then $\Delta W_{i,t-1}$ is a valid instrument for the variables in levels[28]. This said, however, one condition that must be satisfied both by first-difference and system GMM estimators is that the errors must not be second order serially correlated. Formally it must also hold the following:

$$E\left[\left(\varepsilon_{i,t}-\varepsilon_{i,t-\tau}\right)W_{i,st-\tau}\right]=0 \quad \text{with} \quad s\geq 2 \qquad (48)$$

7.3 The empirical model

We are interested in testing one of the main predictions of the theoretical model we built in previous sections. In particular, our hypothesis is contained in eq. (46) in which we put in relation the relative gap in GDP across regions with their initial technological levels, their specific human capital composition and with the institutional quality levels.

As pointed out before, the theoretical model predicts that an increase in the fraction of skilled workforce will be growth enhancing and conductive to

[28] The new estimator builds on a system of two equations (the original and a transformed one) and it is nowadays known as "system GMM".

convergence in income levels across regions. Viceversa, increasing the unskilled content of the workforce will be growth detrimental and conductive to larger GDP gaps in the long run across regions with the follower converging towards lower GDP steady state levels. Also, an increase in the institutional quality of the region/province is expected to impact positively its GDP level and be conductive to convergence to the frontier's GDP levels.

The econometric specification we choose to use is a simplification of eq. (46) and takes the following form:

$$GDP\ gap_{i,t} \;=\; c + \beta_1 SK + \beta_2 Education_{i,t-\tau} + \beta_3 GDP_{i,t-\tau} + \mu_i + \upsilon_{i,t} \quad (49)$$

where we define the *GDP gap* as the log of the ratio between the GDP of each observed region w.r.t. to the value for Madrid which we assume to be our empirical leader region. The *initial GDP*, is inserted in our specification in order to control for the initial development stage of each reagion. This is to say that we control for initial income differences across regions in order to properly isolate the partial contribution of human capital composition in the definition of long run GDP gaps. *Education* will be the focus of our analysis proxying for regional and province differences in skill levels. Also, SK represents Social Capital and it will be used in the province-level analysis to proxy for institutional quality.

7.4 Econometric results

7.4.1 Regional results: Pooled OLS

As a preliminary check of the theoretical results of our model assumptions we decided to run a pooled OLS regression of the specification proposed in eq. (49).

The dependent variable, the GDP gap of each region w.r.t. the leader, is regressed on the educational attainment levels and on initial GDP levels. Results look encouraging even if the empirical methodology - pooled OLS - is probably not adequate in our context due to the very likely presence of endogeneity of the explanatory variables, human capital, w.r.t. GDP levels.

In the first column we decided to examine all the educational attainments at once even if this may create multicollinearity problems since the variables are likely to be highly correlated one another. In fact, in the first column of table 1 only the last two coefficients (those for *L1* and *L21*) are statistically significant. This said they actually enter with expected negative sign indicating how an increase in the unskill-content of the workforce is associated to an increase of the GDP gap across regions (followers w.r.t. the leader Madrid) in the long run.

In the second column, then, we decide to focus on a small subset of explanatory variables in order to better distinguish among educational levels. Hence we use only higher education-secondary level (*L32*) and lower secondary (*L21*) as a proxy of the skilled and unskilled fractions of the population. Here, the results are clearer and coefficients enter with strong statistical significance. Here below in table 1:

[TABLE 1 ABOUT HERE]

The coefficient for "high education" enters with the expected positive sign indicating the positive role played by higher education in the reduction of the GDP gap across regions. At the same time, the coefficient for lower secondary education is instead negative confirming our initial assumptions. The same result holds when instead of considering lower secondary education we insert upper secondary educational attainment in the third column. Again the coefficient for higher education scores a positive sign while the one for upper secondary (proxying for low education) is negative.

As pointed out before, however, these estimates are likely to be biased due to endogeneity of the regressors w.r.t. the dependent variable. For this reason we move to the use of Difference and System GMM estimators which allow us to build internal instrumental set to address the problem of endogeneity of the regressors and provide consistent and unbiased estimates. In the next sections below we propose the results.

7.4.2 Econometric approach

The Arellano-Bond (1991) and Arellano-Bover (1995)/Blundell-Bond (1998) dynamic panel estimators have nowadays become increasingly popular. The two estimators are especially designed for situations in which the number of individuals within the panel is relatively larger than the time dimension. Also, and this comes at a hand in our context, these estimators are well suited when the left-hand-side variable (which is dynamic in nature) depends on its own past realizations as well as on other independent variables which are however not strictly exogenous.

The so called Difference GMM estimator relies on the transformation of all regressors, usually by differencing them, and it uses the Generalized Method of Moments (Hansen 1982). The System GMM estimator, instead, relies on the additional assumption that is that first differences of instruments are uncorrelated with the fixed effects 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 in a simpler Difference GMM estimation. Here below therefore we propose the System GMM results of our baseline specification in eq. (49). The first two columns refer to the one-step System GMM estimation while the third one is the result of a two-step robust estimation.

The two-step variant of the System GMM makes use of an "optimal" weighting matrix which is the inverse of the estimate of $Var[z\prime\varepsilon]$, where z is the instrument vector and ε the error term. This 'optimal' weighting matrix makes two-step GMM asymptotically efficient. The nice property of the two-step estimation, however, comes with the cost of having to estimate the vector of moments between instruments and errors, which are fourth moments of the underlying distributions. In small samples, as argued by (Hayashi, 2000, p. 215) it can be unfeasible to estimate such vector so that the estimation of such an optimal weighting matrix may be singular.[29]

Also, for all the estimation which will follow, we will make use of an additional correction to the estimated standard errors. In the one-step SysGMM estimation we always correct for the presence of any pattern of heteroskedasticity and autocorrelation within panels (in table 2, for instance, this correction is run for column *(i)* and *(ii)*). These estimators are named robust (see footnote in each table).

For all the two-step estimations, instead, the standard covariance matrix should be already robust in theory, but typically yields standard errors that are severly downward biased (Arellano and Bond 1991; Blundell and Bond 1998). For this reason, we use the correction to the two-step covariance matrix proposed by Windmeijer (2005)[30] and then made available in STATA by Roodman (2006). This correction, is argued, can make the two-step robust estimation more efficient than robust one-step especially for system GMM. For this reason this latter will be our preferred econometric specification.

Another important issue, which is severly underestimated in the empirical literature which deals with Difference and System GMM estimators is the possible overfitting of the endogenous variable by a too numerous instrumental set. As pointed out by Roodman (2008), the software routines which are usually employed for the computation of these estimators produce an excessive number of instruments which may actually overfit the endogenous variable both in Difference and System GMM. The econometrician, therefore, must pay much

[29] As pointed out by Roodman (2006): " *When S is singular, carrying out the second estimation step in FEGMM then requires the use of a generalized inverse of S. In Difference and System GMM, this breakdown tends to occur as j approaches N (Arellano and Bond, 1998), a fact that has also contributed to the idea that N is a key threshold for safe estimation. The recourse to the generalized inverse does illustrate how a high instrument count can lead two-step GMM far from the theoretically efficient ideal. But it does not make two-step GMM inconsistent—the choice of weighting matrix does not affect consistency—so it is not obvious that j = N is a key threshold for reliability*".

[30] 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*".

care in the definition of the instrumental set. If the endogenous variable is overfitted by too many instruments the estimator will produce unplausibly good Hansen-test results with a P-value very close to 1. As a rule of thumb it is argued we should constraint the number of instruments to be not more than the number of individuals in our sample. We follow strictly this rule in our estimates both for the regional and provinces case so our restults are robust to the argument of instrumental prolification which, as we pointed out, is nowadays usually underestimated.

7.4.3 Regional results: System and Difference GMM estimations

For all specifications (one-step and two-step system GMM estimations), the coefficient for second-higher education *(HK32)* show the expected sign and it is statistically significant at 1 percent confidence level. This result argues for the positive and important impact that the high skilled margin of the workforce would play in the process of GDP convergence at the regional level as hypothesized in the theoretical model.

The lowest educational categories (*HK1* and *HK21*), primary schooling and lower secondary are found, instead, not to be statistically significant pointing to a weak role played by these educational categories (when examined altogether) on economic growth and regional convergence mechanisms.

The intermediate educational attainment categories, instead are statistical significant. The upper secondary category *(HK22)*, proxying for professional training, college and technical college educational levels (FP I and FP II) show a positive sign while *(HK31)* is negative and statistically significant (Diploma degree).

[TABLE 2 ABOUT HERE]

Another explanation may be that those two educational categories should be merged, representing the overall intermediate educational attainment level. We do so in the next results were we aggregate in different ways the human capital attainment levels in order to check the robustness of the results obtained on the high skill margin of the workforce.

[TABLE 3 ABOUT HERE]

On one hand, the positive sign for *(HK22)* is probably due to the peculiar preparation of those attending the technical college who productively enter the job market. In a context of technology imitation/adoption (as it it is in our model) their specialized know-how may be assimilated to that of higher educational levels (those coming out from the professional training are usually engineers and technics) in the role that they may play in the adoption and development of new technologies (the productive engine of both the leader and follower regions).

On the other hand, instead, those attending the Diploma degrees are usually receiving a less specialized and technical-intensive education (but usually broader in contents) and they better fit in the definition of lower technically skilled workers. These workers, not having had, or having had less, technical-intensive preparation which may be spent in technical reverse engineering or adoption of new technologies, are therefore as in the theoretical model impacting negatively growth prospect.

In tables 5 and 6 we try different alternative aggregations for the analyzed educational attainment levels. In column (i), (ii) nad (iii) we aggregate the top educational margin by summing up the *HK32* and *HK31* categories and leaving the remaining *HK1*, *HK21* and *HK22* in the broader "lower" educational category. The results for this aggregation (which only differ in the type of estimation procedure and on the insertion of time dummies) show again how the top educational margin (even if differently aggregated) remain statistically significant at 1 percent level showing a positive coefficient. Instead, the lower bound is always not statistically significant pointing to the weak impact of the low skilled fraction of active population to convergence across spanish regions in GDP levels.

As argued before, however, this is not the only possible educational aggregation. We tried, therefore, to aggregate the intermediate educational levels (*HK22* and *HK31*) into a unique category and re-run the System GMM estimations looking at 4 educational categories, primary or basic schooling (*HK1*), lower secondary (*HK21*), intermediate (*HK22*+ *HK31*) and higher education (*HK32*).

Results again seems to confirm the uneven and non-lineal impact that human capital composition has on GDP convergence across spanish regions. In particular, *HK32* is again statistically significant and positive while the impact of the intermediate educational category (the aggregation of *HK22* and *HK31*) is this time not statistically different from zero. Not surprisingly, instead, basic education scores a positive and statistically significant coefficient pointing to the need of some degree of education in order to positively grow in the medium-long run.

[TABLE 4 ABOUT HERE]

7.4.4 Provinces results: System and Difference GMM estimations

The results at the regional level are interesting *per se* when pointing to the important role that high skilled workers may play in the process of technological and GDP catch-up. Nonetheless, the analysis at this aggregation level brings about some shortcomomigs. The first of these is that the sample size is reduced to 119 observations. The second is that, due to this small sample, we are not able to introduce into the model any proxy of institutional quality differences across regions for which we have reduced even more the sample size.

The analysis at the province level allows us to address these two shortcomings by making use of a different (larger) database and therefore, also, to check the sensitivenness of the results to the change in the aggregation level as well as to the change of data source and explanatory variables. The econometric approach here used will be the same applied to the regional case. Hence, our preferred estimation will be the two-step System GMM with the correction proposed by Windmeijer (2005) even if we will propose also additional checks with the one-step estimation and Difference GMM.

First, we start with the analysis of the impact of the disaggregated human capital attainment levels on GDP gaps the province level.[31] As pointed out before, we are now able to propose the results by controlling for the differences in the quality of the economic environment (what it is institutions in the theoretical model) by proxying for each province's social capital endowment. The assumption is that a higher level of social capital will be growth beneficial and therefore associated to a reduction in the GDP gaps across provinces.

In column (i) of table 5 we propose the one-step robust SysGMM estimation of the disaggregated human capital categories. The results show again the non-lineal impact of human capital educational levels on GDP convergence. Basic/primary (*HK2*) and higher education (*HK5*) show a positive and statistically significant coefficient estimated at 1 percent confidence level. Intermediate educational levels,instead, show the expected negative sign with their coefficients estimated also at 1 percent confidence intervals. Results are robust to the econometric estimation specification. In column (ii) we propose the two-step robust SysGMM estimation for which results are qualitatively unchanged.

In column (iii) and (iv) we insert the proxy for social capital. The coefficient for social capital is, as expected, positive and statistically significant at 1 percent significance levels. This result shows how, for those provinces in which trust and economic cooperation are more developed (proxying for the quality of provinces' institutions), the GDP convergence process is actually faster.

Regarding the impacf of human capital composition we find again that the high skill margin (*HK5*) of the workforce impact positively GDP convergence.

[31] Again, the leader province will be that of Madrid.

Also, the magnitude of the coefficient seems not to be sensitive to the insertion of the social capital control. This may be seen as an indirect proof that the exclusion of this exaplanatory variable in the regional analysis may have not actually severely biased those coefficients related to human capital.

The intermediate educational attainments are found to be negatively correlated to GDP gaps reduction as expected, while basic education is positive and statistically significant. The results are robust to the econometric specification applied (both to one-step and two-step SysGMM estimators).

[TABLE 5 ABOUT HERE]

We hence moved to the analysis of the impact of human capital composition and social capital by aggregating the educational attainment levels as we did for the regional case. In table 6 and 7 we propose the results for different aggregation measures and econometric estimators.

[TABLE 6 ABOUT HERE]

In columns *(i)* to *(iv)* we propose the results for three main educational cateogries. Basic education correspond to (*HK2*), intermediate education is instead represented by (*HK3+HK4*) while higher education is (*HK5*). The results are proposed with and without controlling for social capital and making use of both two-step robust SysGMM and Difference GMM.

The results confirm our hypothesis for all specifications and econometric estimators. The higher fraction of human capital (the high skill intensive margin of the active population) always enters with a positive a statistical significant coefficient. This is so when we insert (or drop) the social capital control. Basic education is again statistically significant and positive while the intermediate educational attainment levels are negative and significant as expected.

Results however may be driven by the particular aggregation we chose for human capital catefories. For this reason, in table 6 we split the sample into two broader categories representing skilled and unskilled workers. In particular we aggregate into the skilled category the two upper categories (*HK5* and *HK4*) adn in the unskilled one the remaining (*HK3* and *HK2*).

[TABLE 7 ABOUT HERE]

The results are robust to different aggregations of human capital levels and to the insertion of social capital controls. The aggregation for the unskilled human capital margin shows a negative impact on GDP convergence and it is statistically significant also when we insert social capital into the regression but in the two-step robust Difference GMM estimation only.[32]

8 Conclusions

The debate over education is probably one of the most recurrent in policy making. From a regional point of view the disparities in educational attainments are sometimes very large with follower regions stuck at relatively low level of development. Also, the role played by technological growth and spillovers is usually seen as one of the main channels through which economies may grow and escape poverty.

With this paper we studied the case of spanish regions and provinces by building a simplified two-region theoretical model where innovation and imitation are performed. Technology spillovers are ignited by the recipient region's ability of adopting the technologies coming from the frontier. This ability is measured in terms of the quality of its human capital. Also, the ability to perform own-based R&D is an increasing function of the human capital of each region.

We merged features from different previous contributions such as Barro and Sala-i-Martin (1997), Helpman (1993) or Grossman and Helpman (1991), Nelson and Phelps (1966) and Behnabib and Spiegel (2005) in order to formalize the cost function and dynamics of the follower region. The relative easiness of imitation, its cost, has been assumed to be a function of the proximity to the technological frontier as well as of the quality of human capital devoted to imitation in the follower region. Also, the growth path of the follower economies is put in relation with its institutional and social capital levels. All these variables have been shown to be crucial in the definition of the optimal growth path for the follower region.

In particular, our model shows, under broad conditions, that an increase in the high skilled share of the total workforce is growth enhancing for both the leader and the follower implying how it is the high skill margin of the workforce the one that should be optimally risen in order to achieve higher growth rates.

In the model we present, somehow, we reconcile two strands of theoretical results. We show how the increase of the high skill content of the follower

[32] We have been unable to produce a consistent two-step robust System GMM estimation with the new human capital aggregations. In particular, even if the signs of the coefficients were those actually expected the Over-ID test was never passed pointing to the weakness of the overall instrumental set. For this reason we switched to the two-step robust Difference GMM estimation which, instead, seems to correctly pass all major significance tests. Social capital is however not statistically different from zero in both specifications.

workforce makes innovation increasingly more profitable at any stage of development such that for high human capital levels innovation will be performed optimally as in Vandenbussche, Aghion and Meghir (2004). At the same time, however, as in the original Nelson and Phelps (1966) hypothesis, an increase in human capital levels will also make imitation and catch-up faster making, among other things, reverse engineering and technology adoption easier for the follower regions.

The same applies to any improvement in institutional quality in region 2 which increases the long run proximity of follower economies to the technological frontier as argued in empirical literature such as Hall and Jones (1999).

We check the main theoretical results of our model on spanish regions and provinces for the period 1960-1997 by making use of a dynamic panel model. Due to the particular nature of our data - the use of educational attainment levels to explain difference of GDP across regions - our model may suffer severely from endogeneity bias.

For this reason we chose to use appropriate econometrics techniques, namely two-step Windmeijer small sample corrected System GMM estimators, to test the hypothesis that increases in the high skill content of regions' human capital stocks are conductive to higher growth and to a higher proximity with the leader in the long run. Hence, we pay particular attention to some of the main econometric issues in the use of these estimators such as the possibility of instrumental proliferation and severe bias of the results and relative tests.

Also, the estimations are run over two different human capital databases and are robust to the insertion of additional control variables such as social capital differences at the province level.

Our results seem to confirm the main hypothesis of the theoretical model. The impact of human capital on the reduction of GDP differential across regions is non-lineal. Higher educational levels enter with a positive coefficient in our regressions indicating how an increase in the high skill content of each regions workforce may be conductive to higher economic growth. Instead, intermediate and lower educational levels seem to negatively contribute to growth in the long run.

Our result is somehow alternative to some recent empirical findings in the regional economic literature such as Diliberto (2006) who seem to point out that only the increase of the primary education has been the engine of catch-up for Italian southern/follower regions in a model of technological convergence. We believe this result to be puzzling somehow. In fact, when we properly deal with endogeneity issues as well as with the persistence of the educational series which may be poor instruments in simple IV estimations, we are able to show that not only basic education enters with a positive sign in the regressions but that much of the GDP convergence is actually exaplained by the higher education margin of the workforce.

Table 1

Dependent Variable: Regional GDP gap	**Pooled OLS**	**Pooled OLS**	**Pooled OLS**
	(i)	*(ii)*	*(iii)*
Log Initial GDP	*.932*	*.916*	*.907*
	*(.023)****	*(.023)****	*(.023)****
HK32			
higher education, second	*-.017*	*.023*	*.031*
	(.019)	*(.010)***	*(.014)***
HK3			
higher education, first	*.029*		
	(.023)		
HK22			
upper secondary	*.007*		*-.044*
	(.031)		*(.017)***
HK21			
lower secondary	*-.044*	*-.044*	
	*(.020)***	*(.011)***	
HK1			
Primary	*-.052*		
	*(.019)***		
C	*.084*	*.028*	*.021*
	*(.028)***	*(.010)***	*(.010)***
R2	*0.97*	*0.90*	*0.97*
n. Obs	*119*	*119*	*119*

****, ** Statistically significant respectively at 1%, 5%*
Standard errors are corrected for heteroskedasticity and reported in parenthesis.

Table 2

Dependent Variable: Regional GDP gap

	System GMM one-step	System GMM one-step	System GMM two-step windmeijer robust
	(i)	(ii)	(iii)
Log Initial GDP	.779 (.077)***	.692 (. 056)***	.701 (.200)***
HK32-higher education, second	.022 (.006)***	.025 (. 004)***	.007 (.035)**
HK31-higher education, first	-.094 (.077)***	-.075 (.014)***	-.024 (.009)**
HK22-upper secondary	.016 (.002)***	.014 (.003)***	.006 (.002)***
Hk21-lower secondary	-.004 (.004)	-.002 (.003)	.005 (.008)
HK1-primary	-.003 (.002)	-.004 (.001)***	-.001 (.001)
C	-2.41 (.271)***	-2.35 (.212)***	-2.44 (.381)***
Arellano-bond test AR(2) p-values	0.129	0.207	0.155
Hansen test for Over-ID	0.816	1.00	0.219
n. Instruments	25	42	19
Time dummies	No	No	Yes
n. Obs	119	119	119

*Note: ***, **,* Statistically significant respectively at 1%, 5% and 10%.*
Robust standard error estimates are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels standard errors and are reported in parenthesis. Two-step System GMM are corrected as in Windmeijer (2005) for finite-sample covariance matrix.

Table 3

Dependent Variable: Regional GDP gap			
	System GMM **one-step**	**System GMM** **one-step**	**System GMM** **two-step** **windmeijer robust**
	(i)	*(ii)*	*(iii)*
Log Initial GDP	*.118*	*.791*	*.777*
	(.090)	*(. 047)****	*(.045)****
HK32+HK31	*.012*	*.005*	*.005*
higher education, (second+first)	*(.005)***	*(. 001)****	*(.001)***
HK22+HK21+HK1	*.003*	*-.000*	*.000*
Upper+Lower secondary	*(.005)*	*(.000)*	*(.000)*
+ primary			
C	*-0.861*	*-2.56*	*-2.51*
	*(.416)***	*(.153)****	*(.137)****
Arellano-bond test AR(2) p-values	*0.054*	*0.338*	*0.319*
Hansen test for Over-ID	*0.297*	*0.783*	*0.783*
n. Instruments	*18*	*13*	*13*
Time dummies	*No*	*Yes*	*Yes*
n. Obs	*119*	*119*	*119*

*Note: ***, **,* Statistically significant respectively at 1%, 5% and 10%.*
Robust standard error estimates are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels standard errors and are reported in parenthesis. Two-step System GMM are corrected as in Windmeijer (2005) for finite-sample covariance matrix.

Table 4

Dependent Variable: Regional GDP gap	**System GMM** *one-step*	**System GMM** *two-step windmeijer robust*
	(i)	*(iii)*
Log Initial GDP	*.538*	*.468*
	*(.071)****	*(.109)****
HK32	*.019*	*.022*
higher education	*(.007)***	*(.009)***
HK31+HK22	*.003*	*.006*
Intermediate education	*(.005)*	*(.007)*
HK21		
Lower secondary education	*-.001*	*-.001*
	(.005)	*(.003)*
HK1		
Basic education	*.006*	*.007*
	*(.002)***	*(.002)***
C	*-2.17*	*-2.51*
	*(.182)***	*(.189)****
Arellano-bond test AR(2) p-values	*0.108*	*0.504*
Hansen test for Over-ID	*0.839*	*0.839*
n. Instruments	*26*	*26*
Time dummies	*No*	*No*
n. Obs	*119*	*119*

*Note: ***, **,* Statistically significant respectively at 1%, 5% and 10%.*
Robust standard error estimates are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels standard errors and are reported in parenthesis. Two-step System GMM are corrected as in Windmeijer (2005) for finite-sample covariance matrix.

Table 5

Dependent Variable: Provinces GDP gap				
	System GMM one-step	**System GMM** two-step windmeijer robust	**System GMM** one-step	**System GMM** two-step windmeijer robust
	(i)	*(ii)*	*(iii)*	*(iv)*
Log Initial GDP	*.568 (.047)****	*.544 (.059)****	*.592 (.049)****	*.567 (.050)****
HK5 higher, secondary	*.298 (.047)****	*.298 (.058)****	*.227 (.064)****	*.252 (.070)****
HK4 vocational training	*-.336 (.051)****	*-.340 (.061)****	*-.379 (.103)****	*-.403 (.118)****
HK3_secundary	*-.072 (.023)****	*-.064 (.028)****	*.004 (.057)*	*.006 (.052)*
HK2-primary	*.161 (.022)****	*.154 (.023)****	*.186 (.033)****	*.187 (.034)****
Social Capital			*.001 (.000)****	*.001 (.000)****
C	*-4.39 (.306)****	*-4.22 (.362)****	*-4.82 (.457)****	*-4.65 (.426)****
Arellano-bond test AR(2) p-values	*0.393*	*0.447*	*0.566*	*0.789*
Hansen test for Over-ID	*0.133*	*0.133*	*0.202*	*0.202*
n. Instruments	*40*	*40*	*44*	*44*
Time dummies	*No*	*No*	*No*	*No*
n. Obs	*400*	*400*	*250*	*250*

*Note: ***, **,* Statistically significant respectively at 1%, 5% and 10%.*
Robust standard error estimates are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels standard errors and are reported in parenthesis. Two-step System GMM are corrected as in Windmeijer (2005) for finite-sample covariance matrix.

Table 6

Dependent Variable: Provinces GDP gap				
	System GMM two-step windmeijer robust	**System GMM** two-step windmeijer robust	**Difference GMM** two-step windmeijer robust	**Difference GMM** two-step windmeijer robust
	(i)	*(ii)*	*(iii)*	*(iv)*
Log Initial GDP	*.600*	*.777*	*.266*	*.131*
	*(.051)****	*(.055)****	*(.025)****	*(.062)***
HK5	*.101*	*.183*	*.068*	*.214*
Higher education	*(.034)***	*(.051)****	*(.023)****	*(.053)****
HK3+HK4 Intermediate education	*-.432* *(.080)****	*-.698* *(.123)****	*-.475* *(.072)****	*-.531* *(.185)****
HK2	*.411*	*.550*	*.069*	*.241*
Basic education	*(.051)****	*(.079)****	*(.079)***	*(.097)****
Social Capital		*.001* *(.000)****		*.000* *(.000)*
C	*-4.19* *(.438)****	*-4.19* *(.438)****	-	-
Arellano-bond test AR(2) p-values	*0.129*	*0.155*	*0.311*	*0.380*
Hansen test for Over-ID	*0.270*	*0.254*	*0.405*	*0.862*
n. Instruments	*47*	*44*	*50*	*19*
Time dummies	*No*	*No*	*No*	*No*
n. Obs	*400*	*250*	*350*	*200*

*Note: ***, **,* Statistically significant respectively at 1%, 5% and 10%.*
Robust standard error estimates are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels standard errors and are reported in parenthesis. Two-step System GMM are corrected as in Windmeijer (2005) for finite-sample covariance matrix.

Table 7

Dependent Variable: Provinces GDP gap						
	System GMM one-step	**System GMM** two-step windmeijer robust	**Difference GMM** one-step	**Difference GMM** two-step windmeijer robust	**System GMM** two-step windmeijer robust	**Difference GMM** two-step windmeijer robust
	(i)	*(ii)*	*(iii)*	*(iv)*	*(v)*	*(vi)*
Log Initial GDP	*.92 (. 022)****	*.925 (.022)****	*.271 (.026)****	*.269 (. 029)****	*.111 (.047)****	*.007 (.029)*
HK4+HK5 Higher education, (second+first)	*.034 (. 028)*	*.034 (.023)*	*.035 (.021)***	*.036 (. 025)*	*.049 (.024)***	*.129 (.025)****
HK2+HK3 secondary+ primary	*-.045 (.027)**	*-.047 (.024)***	*-.392 (.079)****	*-.047 (.009)****	*.062 (.051)*	*-.390 (.151)***
Social capital					*.001 (.007)*	*-.006 (.009)*
C	*-6.52 (.182)****	*-6.50 (.188)****	-	-	*-1.56 (.368)****	-
Arellano-bond test AR(2) p-values	*0.926*	*0.909*	*0.215*	*0.222*	*0.660*	*0.419*
Hansen test for Over-ID	*0.672*	*0.672*	*0.112*	*0.112*	*0.038*	*0.531*
n. Instruments	*42*	*42*	*37*	*37*	*28*	*14*
Time dummies	*Yes*	*Yes*	*No*	*No*	*No*	*No*
n. Obs	*400*	*400*	*400*	*400*	*250*	*200*

*Note: ***, **,* Statistically significant respectively at 1%, 5% and 10%.*
Robust standard error estimates are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels standard errors and are reported in parenthesis. Two-step System GMM are corrected as in Windmeijer (2005) for finite-sample covariance matrix.

References

[1] Abramovitz, M. (1986). “Catching Up, Forging Ahead, and Falling. Behind”. Journal of Economic History 46, 385-406.

[2] Acemoglu D., P. Aghion and F. Zilibotti (2006). "Distance to Frontier, Selection, and Economic Growth", Journal of the European Economic Association 4 (1), 37-74

[3] Acemoglu Daron, Simon Johnson and James A. Robinson (2001), "The Colonial Origins of Comparative Development: An Empirical Investigation", American Economic Review, volume 91, pp. 1369-1401.

[4] Acemoglu Daron, Simon Johnson and James A. Robinson (2005), "Institutions as the Fundamental Cause of Long-Run Growth", Handbook of Economic Growth (Philippe Aghion and Stephen Durlauf, eds., region 1 Holland)

[5] Aghion, P. and P. Howitt, (1992). “A Model of Growth Through Creative Destruction” Econometrica, 60 (2).

[6] Aghion, P. and P. Howitt (2005) "Appropriate Growth Policy,". Forthcoming in the Journal of the European Economic Association.

[7] Arellano, M. (2003a) Panel Data Econometrics, Oxford University Press, Oxford.

[8] Arellano, M. (2003b) ‘Modeling optimal instrumental variables for dynamic panel data models’, Working Paper 0310, Centro de Estudios Monetarios y Financieros, Madrid.

[9] Arellano, M., and S. Bond. (1991). ‘Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations’, Review of Economic Studies, Vol. 58, pp. 277–297.

[10] Arellano, M., and S. Bond. (1998). ‘Dynamic panel data estimation using DPD98 for Gauss: a guide for users’, available at ftp://ftp.cemfi.es/pdf/papers/ma/dpd98.pdf.

[11] Arellano, M., and O. Bover. (1995). ‘Another look at the instrumental variables estimation of error components models’, Journal of Econometrics, Vol. 68, pp. 29–51.

[12] Barro, Robert J., and Xavier Sala-i-Martin, (1997), “Technological Diffusion,Convergence and Growth,” Journal of Economic Growth, 1, 1-26

[13] Barro, Robert J., and Xavier Sala-i-Martin, (1995), Economic Growth.

[14] Basu, Susanto, and David N. Weil, (1998), “Appropriate Technology and Growth,” Quarterly Journal of Economics, November, 113(4), 1025-54.

[15] Benhabib, Jess and Mark M. Spiegel. (1994), "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data," Journal of Monetary Economics, 34, 143-173.

[16] Benhabib, J. and M. Spiegel. (2005). "Human Capital and Technology Diffusion", in Aghion P. and S. Durlauf (eds), Handbook of Economic Growth, Elsevier

[17] Bils, Mark, and Peter J. Klenow, (2000), "Does Schooling Cause Growth?," American Economic Review, December, 90(5), 1160-83.

[18] Blundell, R., and S. Bond. (1998). 'Initial conditions and moment restrictions in dynamic panel data models', Journal of Econometrics, Vol. 87, pp. 115–143.

[19] Blundell, R., and S. Bond. (2000). 'GMM estimation with persistent panel data: An application to production functions', Econometric Reviews, Vol. 19, pp. 321–340. 30

[20] Blundell, R., S. Bond, and F. Windmeijer. (2000). 'Estimation in dynamic panel data models: improving on the performance of the standard GMM estimator', in Baltagi B. (ed.), Advances in Econometrics, Vol. 15, Nonstationary Panels, Panel Cointegration, and Dynamic Panels, JAI Elsevier Science, Amsterdam.

[21] Caselli F. (2005). "Accounting for Cross-Country Income Differences," NBER Working Papers 10828, National Bureau of Economic Research

[22] Caselli, Francesco & Wilson, Daniel J., (2004). "Importing technology," Journal of Monetary Economics, Elsevier, vol. 51(1), pages 1-32, January

[23] Castelló, A. (2006). " On the distribution of Education and Democracy" Institute of international Economics, working paper, University of Valencia.

[24] Coe, David T. and Elhanan, (1995), "International R&D Spillovers," European Economic Review, May, 39(5), 859-87

[25] Connolly M. and D. Valderrama. (2005). "North-South technological diffusion and dynamic gains from trade," Working Papers in Applied Economic Theory, Federal Reserve Bank of San Francisco.

[26] de la Fuente, A. and Doménech R.(2006) "Human capital in Growth Regressions: How much difference does data quality make?" Journal of European Economic Association, 4(1), 1-36

[27] de la Fuente, A., Doménech R., and J.F. Jimeno (2003). "Human capital as a factor of growth and employment at the regional level. The case of Spain". IAE WP 610.04

[28] Diliberto, A. (2006). "Education and Italian Regional Development",Economics of Education Review, Vol. 27, No.1

[29] Dollar, D. and A. Kraay (2003). "Institutions, trade, and growth" Journal of Monetary Economics, Elsevier, vol. 50(1), pages 133-162

[30] Frankel J. and D. Romer, (1999), "Does Trade cause Growth? ", American Economic Review. 89(3):. pp. 379-99.

[31] Gallini, N. (1992) "Patent Policy and Costly Imitation", The RAND Journal of Economics 23, 52-63

[32] Gerschenkron, A., (1962), Economic backwardness in historical perspective, Cambridge, Belknap Press of Harvard University Press

[33] Grossman, G. and Helpman E. "Innovation and Growth in the global economy". Cambridge MA:MIT press

[34] Hall, Robert E. and Charles I. Jones, (1999), "Why Do Some Countries Produce So Much More Output Per Worker Than Others?," Quarterly Journal of Economics, February, 114(1), 83-116, 61, 1247-80

[35] Keefer P. and S. Knack. (1997). "Why Don't Poor Countries Catch Up? A Cross-National Test of an Institutional Explanation". Economic Inquiry 35, 590-602.

[36] Keefer P. and S. Knack (2002). " Polarization, Politics and Property Rights: Links Between Inequality and Growth", Public Choice 111, 127-154.

[37] Nelson, Richard R. and Edmund S. Phelps (1966), "Investment in Humans, Technological Diffusion, and Economic Growth," American Economic Review, 56, 69-75

[38] North, D. (1990)., "Institutions, Institutional Change, and Economic Performance, Cambridge", Cambridge University Press

[39] Olson M., N. Sarna and A. Swamy. (2000)."Governance and Growth: A Simple Hypothesis Explaining Cross Country Differences in Productivity Growth", Public Choice, 102, 341-364

[40] Parente, S. L., and E. C. Prescott (2000), Barriers to Riches, Cambridge, MA: MIT Press.

[41] Psacharopoulos, George. 1994. "Returns to Investment in Education: A Global Update", World Development 22(9):1325-43

[42] Roodman, D (2006). "How to Do xtabond2: An Introduction to "Difference" and "System" GMM in Stata," Working Papers 103, Center for Global Development

[43] Roodman, D. (2007). "A Note on the Theme of Too Many Instruments," Working Papers 125, Center for Global Development.

[44] Sachs, Jeffrey. D. and Andrew M. Warner, (1997), “Fundamental Sources of Long-Run Growth,”. American Economic Review, May, 87(2), 184-188.

[45] Windmeijer, F. (2005). ‘A finite sample correction for the variance of linear efficient two-step GMM estimators’, Journal of Econometrics, Vol. 126, pp. 25–51.