Technology Catching-up and the Role of Institutions

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Abstract

The aim of the paper is to investigate the role played by differences in Institutional Quality on the process of technology catch-up across countries. Empirical evidence shows how countries endowed with better institutions are those more rapidly closing the gap with the frontier. Conversely, countries lacking a minimum institutional level are shown to diverge in the long run and not to catch-up. Interestingly, technology catch-up seems to account for the observed β-convergence across countries. We also investigate the role of specific policy arrangements within the catching-up process finding how a tightening of Property Rights seems to reduce followers' ability to imitate while trade-oriented policies benefit both leaders and followers.

JEL: O33, O38, O40

KEYWORDS: TFP, catch up, growth, institutions

1 Introduction

In 1966 Richard Nelson and Edmund Phelps formalized one of the most appealing ideas in modern economic growth, that of technological catching up across countries. The idea, which is originally due to Gerschenkron (1962), is at the same time powerful and simple. Countries lagging behind the world technological frontier may reduce their gap from it by simply imitating technologies discovered in leader countries. As in Barro and Sala-i-Martin (1997) this happens since the costs of imitation in the follower country are usually lower than those of innovation at the frontier. Hence, the wider the gap and the more the scope for adopting new technologies and therefore the higher, ultimately, the technology growth rates of the lagging country. Crucially, however, the catch-up process is not immediate. Simply lagging behind the leader is not a sufficient condition in order to ensure high growth and catch-up.

Nelson and Phelps (1966), and later Abramovitz (1986) rearranged the catching up hypothesis of Gerschenkron (1962) suggesting how the rate at which the technological gap is closed should be linked to the followers' ability to receive technology flows from the frontier, that is, in their particular case, a function of each country's human capital stock. More recently, the work of Benhabib and Spiegel (1994, 2005) empirically grounded the Nelson and Phelps (1966) hypothesis showing how differences in human capital stocks may help explaining the observed differences in the speed of technology catch-up across countries.

Crucially for the motivations of our own contribution stands the fact that even after accounting for human capital differences across countries large differentials in productivity levels and growth rates are still observed[1]. Interestingly, for example, no correlation is found on average between a country's distance from the technological frontier and its GDP or TFP growth rates even when human capital differences are taken into account in the computation of the gap. We believe this is suggestive of the fact that some other variables may be fundamental, along with human capital, in igniting and promoting TFP growth and catch-up across countries.

In what follows we will argue how Institutional Quality differences explain, to a large extent, the differences in the speed by which countries imitate and adopt technologies discovered at the frontier. Hence, we build on the recent contributions of Hall and Jones (1999) and Acemoglu, Johnson and Robinson (2001), by assuming not only that good institutions are associated to better economic performances but also that they represent the necessary condition for technology adoption and catch up of follower countries.

With our work we aim at merging two strands of literature by testing the impact of institutional quality within the technology catching up framework. The main question we pose here is the following: do countries endowed with better institutions experience a faster rate of technological catch-up than those with poor institutions? If yes, is there a particular institutional arrangement or policy which is more willing to deliver this outcome?

Noticeably, despite its importance, previous literature has not provided yet a clear empirical evidence of whether (and how) differences in Institutional quality (IQ from now on) play a role in the speed and diffusion of technology from the world frontier to the laggard countries. Among the very few exceptions stand the works of Knack and Keefer (1997) and of Olson, Sarna and Swamy (2000). Both of them own major drawbacks which we target in our own contribution. The first reason of concern is that these previous contributions do not properly control for simultaneity bias in their estimates. Instead, we employ appropriate

[1] See for example, Hall and Jones (1999), Easterly and Levine (2000), Klenow and Rodriguez-Clare (1997) or Caselli (2005).

Instrumental Variables techniques, as it has become increasingly popular in this kind of literature[2], not only to control for endogeneity of productivity w.r.t. institutions but also to address measurement errors problems. Secondly the lack of robust data on institutional quality used previous contributions makes OLS results questionable. Due to this problem, for example, previous empirical works controlled for the impact of institutional quality on technology transfers by using end of the period values for institutions, instead of averages for the whole period, hence *de facto*, not properly testing the catching-up hypothesis.

From a methodological point of view we will rely on the catching-up framework proposed by Benhabib and Spiegel (2005) for a variety of reasons. The most important is that this can be easily generalized to a vast range of hypotheses by including or excluding variables which we may repute to play a significant role in the definition of TFP growth rates or technological differentials across countries. Secondly, this framework is parsimonious enough in the number of variables to allow us to address the problem of endogeneity between TFP and institutional quality quite straightforwardly.

Nonetheless, differently from Benhabib and Spiegel (2005), we will opt for the use of TFP estimates (proxying for countries' technology stocks) which already control for cross country differences in human capital stocks. TFP is in fact computed as a residual from a growth accounting exercise which inserts human capital as a factor of production within the Cobb-Douglas production function along with physical capital and labor. Resulting differences in TFP levels calculated this way, therefore, will not reflect differences in human capital or skills accumulation across countries since these have already been controlled for in the computation of the residuals. Hence, if any, technological catching-up will have to be explained by variables others than human capital. As said, we propose institutional quality differences as an explanation for the differences in the speed of technology adoption across countries.

The remainder of the paper is the following. In section 2 we review the link between institutional quality and technology transfers by giving some example of how good institutions may lead to faster technology adoption. In section 3 we deal with the technology catching-up model specification. Here we explore why a logistic functional form may show some advantages w.r.t. a simpler confined exponential function in modeling the diffusion of technology from the frontier to the followers. In particular we show how the former provides some more restrictive catch-up conditions which we argue to better mimic real data. In section 4 we briefly review some data issues while in section 5 we provide regression results of the technology catching-up specification. In section 6 we make use of the threshold analysis proposed by Benhabib and Spiegel (2005) by which we are able to define what are the countries not showing catch-up with the leader and under what conditions this theoretically happens. A substantial part of the paper will be devoted to the extensions of the technology catching-up model. In section 7 we will try to assess what the institutional arrangements particularly affecting technology flows from leader to followers are. In particular we will be looking at the consequences on productivity growth of tightening or relaxing some policies (such as the enforcement of property rights or a country's trade openness) which previous theoretical literature has highlighted as fundamental for technology change and economic growth. At the end some conclusions.

[2] See for example Hall and Jones (1999), Acemoglu et al. (2001) and many others.

2 From Institutional Quality to Technology Transfers

Technology transfers and catch-up do not happen spontaneously. As emphasized by Abramovitz (1986), being a laggard carries a *potential* for rapid advance. This potential, however, may remain unexpressed when the recipient country does not own the appropriate characteristics to exploit it. As pointed out by Abramovitz (1986) and Nelson and Phelps (1966), the opportunity for rapid growth is taken by those who owns specific qualities such as technical competencies or political, commercial, industrial and financial developed institutions.

Hence, before turning to the model estimations we propose a simple correlation tests on some of the main variables we will be using throughout this work in order to get intuitive insights on what the underlying relations across these variables are. The variables in the correlation matrix proxy for (i) the average institutional quality (Economic Freedom of the World index, EFW) [3], (ii) TFP gap in the initial year[4], TFP and GDP per capita annual growth rates.

Table 1: Correlation matrix

	TFP growth 1970-200 (annual)	GDP growth in PPP 1970-2000	Institutional Quality average 1970-2000	TFP(i)/TFP(US) Technology gap
TFP growth 1970-200 (annual)	1			
GDP growth in PPP 1970-2000	0.866	1		
Institutional Quality average 1970-2000	0.543	0.554	1	
TFP(i)/TFP(US) Technology gap	0.074	0.084	0.555	1

The correlation between TFP and GDP per capita growth is, as expected, very high. Also the correlation matrix reveals how countries with better institutions are also those which are growing faster both in terms of productivity and GDP per capita with a correlation index higher than 0.5 in the two cases. Of crucial relevance for our work is, however, the relationship between productivity growth and the technological gap from the frontier. The correlation index clearly shows how being a follower country (lagging behind the frontier) is not a sufficient condition *per se* in order to experience higher GDP and TFP growth rates than other countries. The correlation between GDP or TFP growth with the initial technology gap is, in fact, close to zero.

Our empirical investigation starts from this result with the aim of investigating the mechanisms and determinants that promote fast technology catch-up in follower countries. In what follows we will suggest how good institutions may be the promoting factor of technology catch-up and test empirically this hypothesis.

From a "technology catch-up" point of view there are several channels through which differences in the quality of institutions may shape the speed and extent of technology adoption. As emphasized, for instance, by Alcalà and Ciccone (2004) or Dollar and Kraay

[3] A full description of the EFW index will be given in the next sections.

[4] The TFP gap is expressed as the ratio of each country's Total Factor Productivity to the U.S. TFP value in the initial year. Growth accounting methodology accounts for the contribution of human capital in the computation of the Solow residual.

(2003) there exists a positive relationship between good institutions, openness to trade and growth. By trading, follower countries are actually enabled to do reverse engineering of the products received in their home countries. Within an autarkic framework both the adoption and imitation of world leading technologies may be much more difficult.

Also, and maybe more importantly, a firm in a follower country may decide to imitate or adopt a new technology (and spend some resources on this process) when it is going to be able to re-sell the adopted technology-item in international markets. As pointed out by Helpman (1993) less developed countries own a relative advantage in manufacturing due to the lower cost of labor. This is reflected in the relatively lower prices of the replicas which allow follower countries to advantageously compete in international markets. Hence, being able to trade freely helps setting some important economic incentives for the adoption and implementation of new technologies in follower countries which otherwise would be missing.

Having good institutions is also important in setting the right economic environment for the domestic R&D sector. Parente and Prescott (1999) explain the huge differential in productivity levels across countries by not well defined property rights and monopoly power which would raise "institutional barriers" to the adoption of new technologies in developing countries. Kaufmann and Kraay (2002) show the existence of a high correlation between the quality of governance and economic performance over 175 countries for the year 2000-01. Knack and Keefer (2002) link social polarization to less secure institutional environments and ultimately to lower output growth rates. Institutional quality seems to be a fundamental variable defining productivity differentials across countries.

Organizational factors such as the incentives to start up a new business, labor regulations, access to credit, control of diversion, property rights enforcement and so on surely play a fundamental role in the possibility for a firm to adopt a new technology and fully exploit its potentials. A country lacking all these institutional elements may not be able to adopt the new technology even in the presence of a qualified workforce. Bailey and Gersbach (1995) or Prescott (1998) point out to, for example, how Ford Europe, differently from Ford U.S.A, failed to adopt the just-in-time production technology from Japan mainly beacuse of the more restrictive labor and market regulations vigent in Europe. Also, they argued how german breweries could not adopt and run the better technologies that are used in the U.S. or Japan (but that paradoxically have been discovered in Germany) because of explicit rules and regulations that govern the production of beer in Germany.

3 The model

We study the role played by institutional quality on the TFP catching up process by means of a logistic model of technology diffusion. The use of this functional form, rather than a simpler confined exponential diffusion process, allows us to control for the appropriateness of institutional quality in the adoption and implementation of technological flows coming from the frontier. Before turning to that, however, we provide a simple theoretical framework apt to study the impact of IQ differences on the mechanism of technology catching up by building upon the analytical formalization of Romer (1990) and Benhabib and Spiegel (2005).

Let us assume the world is of two countries denoted by $i = 1, 2$ in which 1 represents the North and 2 is the South. The production function for each country takes the usual Cobb-Douglas form as follows:

$$Y_i(t) = K_i^{\alpha}(t)[A_i(t)L_{y,i}(t)^{1-\alpha}] \quad (1)$$

where, as in the endogenous growth model of Romer (1990), $L_{y,i}$ represents the fraction of labor used in the production of good Y in country i. Both North and South run an innovative sector. That is, the law of motion for the stock of knowledge in the two countries is given by a Romer-type function as follows:

$$\dot{A}_i(t) = \delta A_i^{\phi}(t)L_{a,i}^{\lambda(i)}(t) \quad (2)$$

where A_i represents the accumulated stock of ideas (or technology). L_a is the fraction of population engaged in the R&D sector producing new technologies. The parameter ϕ captures the returns from previously accumulated technology stocks on the change of A while λ captures the returns of the R&D sector. As a simplifying assumption we assume ϕ to be the same across countries.[5]

Instead, we leave the parameter λ, the productivity of the R&D sector, to change accordingly to country-specific conditions such as institutional quality. The intuition behind this assumption is rather simple. Assume, for example that the same share of researchers is engaged in the R&D sector in the North as in the South. Better institutional quality in the North may push Northern researchers to be more productive than Southern's ones[6]. This is to say that, in our settings, differences in IQ across countries incentivize researchers differently determining higher returns in one country w.r.t. the other even in a situation where the relative size of the R&D sector is the same across countries.[7]

Along the BGP, it can be shown that economies which only innovate grow at a constant rate given by the following:

$$\gamma_{A,i} = \frac{\lambda(i)n}{1-\phi} \quad (3)$$

where n represents the growth rate of population which, for simplicity, we assume to be the same across countries. As pointed out before institutional quality affects the returns to the R&D sector. In particular we assume the following:

$$\lambda(1) = f(S_1) \quad (4)$$

$$\lambda(2) = f(S_2) \quad (5)$$

[5] That is, given the same amount of accumulated stock of technology in two different countries, the intensity of the returns stemming from it will be the same across countries. On this see the discussion of Jones (2002) p.99.

[6] That is, even if $L_{a,1} = L_{a,2}$, it needs not to be the case that $\lambda(1) = \lambda(2)$. Instead we will assume below that the parameter λ is a function of country specific institutional quality. Hence, in the particular example above we assumed $\lambda(2) < \lambda(1)$ where better incentives to research in the North country lead to higher returns to productivity w.r.t. South.

[7] This reasoning is consistent with the critique made by Jones (1995) on the standard endogenous growth model of Romer (1990) or Aghion and Howitt (1992) about the "scale effects" of R&D effort on productivity and TFP growth. If in Romer or Aghion and Howitt's settings doubling the effort in R&D also doubles the growth of producitivity, this need not to be the case in our framework where the growth of productivity is a function of the country institutional quality. Also, our simple modification to the standard endogenous growth model helps to relax the counterfactual conclusion of Jones (1995) in which the TFP growth rate of a country is ultimately only a function of the growth rate of its workforce.

where, S defines the country specific institutional quality. In this framework the North represents the technological "leader" because $\lambda(1) > \lambda(2)$ while the South will be the "follower"[8]. More formally we assume the following:

$$\lambda(1) = f(S_1) \Longrightarrow \gamma_{A,1} = \frac{\lambda(1)n}{1-\phi} = g(S_1) \tag{6}$$

$$\lambda(2) = f(S_2) \Longrightarrow \gamma_{A,2} = \frac{\lambda(2)n}{1-\phi} = g(S_2) \tag{7}$$

Hence, up to now we set the conditions for which the South grows slower than the North from which it is progressively diverging due to the institutional quality gap $S_1 > S_2$. [9]

This is not the whole story however. Countries need not to diverge in the long-run thanks to the possibility of technology adoption from the world frontier. Let us assume, in fact, that the South is able to imitate technologies from the North[10]. The growth rate of South should be then modified as follows:

$$\gamma_{A,2}(t) = g(S_2) + c\left(\frac{1}{v_2}\right)\left[\frac{A_1(t)}{A_2(t)} - 1\right]\left(\frac{A_2(t)}{A_1(t)}\right) \tag{8}$$

As shown in eq. (6) and eq.(7) $g_i(S_i)$ represents the long run growth that the economy i would experience in the absence of technology flows This is assumed to depend on each country's specific institutional quality[11]. When, instead, we allow for technology flows from the technological frontier the growth rate of the follower is augmented bt the $c(\frac{1}{v_2})\left[\frac{A_1(t)}{A_2(t)} - 1\right]\left(\frac{A_2(t)}{A_1(t)}\right)$ term which captures the technology catching up effect. $c(\frac{1}{v_2})\left[\frac{A_1(t)}{A_2(t)} - 1\right]$ represents the rate of technology diffusion from the leader country (1) to the follower (2).

Crucially, the rate at which the technology gap is closed is, in our formalization, a positive function [12] of the follower institutional quality. Here, v_2 represents the cost for the South country of imitating a technology discovered by the North. As in Barro and Sala-i-Martin (1997), in fact, we assumed here that the follower country, in order to copy leader's technologies, incurs in some income outlay v_2 which represents the cost of imitation. The cost of imitation is here assumed to be an inverse function of institutional quality S,that is, $v_2 = S_2^{-1}$. As pointed out by Hall and Jones (1999), for example, *"in addition to its direct effects on production, a good social infrastructure may have important indirect effects by encouraging the adoption of new ideas and new technologies as they are invented*

[8] We will use the terminology "leader" and North interchangeably in the rest of the paper. The same applies to "follower" and South.

[9] Noticeworthy, institutions are here assumed to be exogenously given. This is the usual assumption in empirical literature such as in Knack and Keefer (1995), Barro (1997), and many others. More likely, instead, as pointed out by Acemoglu (2004), institutions are endogenous and determined by collective choices or by the allocation of political power based on the economic interests of powerful political lobbies. However, Acemoglu (2004) also points out how a complete theory on the causes of institutional differences across countries is still missing and invoked. This task, even tough of much interest, is however far beyond the scope of the current paper.

[10] In order to keep the reasoning as simple as possible we eliminate the possibility that the leader may imitate technologies from the follower as in Barro and Sala-i-Martin (1997) where the pool of blueprints known by the South is a subset of those known by the North.

[11] This is perfectly consistent with some recent empirical evidence shown by Hall and Jones (1999), Alcalà and Ciccone (2002) or Dollar and Kraay (2002) which empirically show how institutional quality plays a fundamental role in defining productivity cross-country differentials.

[12] We assume both g and c to be increasing functions.

throughout the world ". Good institutions facilitate both specialization and flexibility such that imitators find it easier to adapt their organizational processes to the new products to be produced eventually paying a lower cost for imitation.

Additionally, countries with better institutions are usually more open to international markets and, hence, able to do more reverse engeneering. That is, economic agents or firms which operate in better institutional frameworks are able to exploit trade spillovers much more than others which operate in countries with poor institutions. The formers, therefore, face lower costs in adopting new technologies or in using the newly produced public knowledge at the frontier. Also, having more stable economic and political frameworks decrease the need for economic agents to spend consistent resources in protecting themselves from activities such as thievery and squatting while it enables them to devote these resources to productive activities such as technology adoption.

The strength of the catching up mechanism is reduced by the term $\left(\frac{A_2(t)}{A_1(t)}\right)$ which dampens the rate of technological diffusion as the distance from the leader increases. As in Benhabib and Spiegel (2005) this captures the logistic diffusion of technology from the frontier to the follower. That is, holding constant the institutional quality of a country, if differences in technological proportions between the leader and the follower are large, the technology diffusion process will be slower reflecting the difficulty of adopting distant and more complex technologies.

Also, the opposite is going to be true, that is, countries near to the technology frontier experience a weaker catch up effect w.r.t. the gains due to innovation (captured by the $g_i(S_i)$ term). This is because, for those being already at the technological frontier, imitation is not as rewarding as innovation.

Define, now, the difference between the growth rate of follower and that of the leader as follows:

$$\gamma_B = \frac{\dot{B}}{B} = \left[\frac{\dot{A}_2}{A_2} - \frac{\dot{A}_1}{A_1}\right] = g(S_2) + c(S_2)(1 - B) - g(S_1) \tag{9}$$

where

$$B = \frac{A_2}{A_1} \tag{10}$$

We study the steady state value for B. Similarly to Benhabib and Spiegel (2005) this is given by the following:

$$B^* = \frac{c(S_2) - g(S_1) + g(S_2)}{c(S_2)} \tag{11}$$

where,
$B^* = \bar{B}$ if $c(S_2) > g(S_1) - g(S_2)$
$B^* = 0$ if $c(S_2) = g(S_1) - g(S_2)$

The steady state assumes a positive value when if $c(S_2) > g(S_1) - g(S_2)$ while if $c(S_2) = g(S_1) - g(S_2)$ the value of B converges to zero[13] and the follower never catches up with the leader. This is an intuitive result. For defined small levels of its institutional quality the follower country will not be able to fill the gap between its growth rate and that of the leader in their respective innovative sectors. Also, having very poor institutional levels

[13]Notice here that B is only defined within the $\Re^+$ set. This implies that the only solution for the steady state when $c(S_2)$ is not greater than $g(S_1) - g(S_2)$ is actually $c(S_2) = g(S_1) - g(S_2)$.

will impede the South to robustly imitate the leader with the overall result of continuously falling behind and never catching up[14].

4 Some data issues

Empirical works concerned with the explanation of cross-country productivities differentials usually face some major data problems. These are, first of all, due to the fact that the measure of productivity or technology (the TFP or Total Factor Productivity used in our work as well) is usually computed as a residual from the observables within a specified production function[15]. Hence, both the assumptions made on the functional form of the production function and those on the variables to be inserted within it may lead, in some cases, to some discrepancy in the TFP estimates[16].

Despite these problems a growing recent empirical literature focused on the determinants of TFP differential across countries. Within this recent empirical literature there are the already mentioned Benhabib and Spiegel (2005), Hall and Jones (1999), Easterly and Levine (2000) and many others. The TFP estimates we use in our work in order to proxy for countries' technology stocks come from the paper of Baier, Dwyer and Tamura (2006). The choice of using their dataset is based on several methodological issues which we believe to be important in our context.

To start with, the authors follow the methodology of Hall and Jones (1999) and Klenow and Rodriguez-Clare (1997) to decompose output into its productive factors and the residual. That is they use income per worker, rather than income per capita, in measuring economic performance. It is assumed the following production function:

$$Y(t) = A(t)F(K(t), H(t)) \tag{12}$$

where the output $Y(t)$ is produced by using the stock of physical capital $K(t)$ and human capital $H(t)$. $A(t)$ represents a Hicks neutral measure of productivity or TFP. If social marginal products equal private ones and there is perfect competition equation (12) implies that:

$$a = y - \alpha k - (1 - \alpha)h \tag{13}$$

where lower case letters denote variables in growth rates while α and $1-\alpha$ represent factor shares. Notice that no particular functional form is specified for the production function such that deviations of social marginal products from private ones may (but this need not to be the case) be captured by changes in TFP[17]. Recent empirical evidence, however, seems to show how these deviations may be negligible. Basu and Fernald (1997) and Basu

[14] It is worth mentioning how this result is peculiar to the functional form chosen for the diffusion of technology. If we chose a confined exponential function in order to model technology flows we would have ended up with a unique positive solution for the steady state of B as shown in Benhabib and Spiegel (2002).

[15] Some new approaches follow a different way in computing TFP. DEA approaches, for example, compute TFP as the distance of each economy from a non-parametrically constructed world frontier. See for example Cherchye and Moesen (2002) or Kumar and Russel (2002).

[16] Caselli (2004) gives a very detailed and useful review of most of the problems arising in the context of productivity measurement. Nonetheless, even after accounting for the majority of these issues he argues how the biggest bulk of economic growth cross-country differentials has still to be explained by productivity (Solow-Residual) differences.

[17] Hall (1990), for instance, points to the fact that, under imperfect competition there exists a gap between price and marginal costs at the firm level. This, in turn, implies that an increase in primary inputs would lead to an increase in productivity uncorrelated to shocks in technology. Basu and Fernald (1997) argue that:

and Kimball (1997), present a growth accounting framework which identifies several non-technological gaps between observed TFP and "pure technology". The authors' empirical results, however, point out how adjusted measure of technology is very close to the usual Solow's technology residual computed by using C.R.S.[18].

A second important reason justifying the use of Baier, Dwyer and Tamura dataset is the particular care used in computing Human Capital series. The stock of Human capital per worker is accurately computed by taking into account both a measure of average nominal education E_d as in Barro and Lee (1993) and an average of years of experience E_x. We argue how, due to this feature, the Baier, Dwier and Tamura measure of Human capital encompasses some of the others previously used in similar empirical literature[19].

From a methodological point of view, as suggested by Benhabib and Spiegel (2005), human capital can either be intended as a factor of production to be inserted into the Cobb-Douglas production function (where, in that case, an increase in H only affects the economy by its marginal product) or as a factor enhancing technological flows across countries where its role, as in eq.(8) is to increase the rate of technology diffusion.

We are agnostic about what the correct interpretation of the role of human capital stocks should actually be. It may be the case that both human capital stocks and institutional quality should be theoretically regarded as distinct factors enhancing technological flows across countries and therefore abstracted from the production function while directed inserted into the catching up regression as a determinant of the speed of technological convergence. However, from a purely econometric point of view, inserting both human capital and institutions into the same regression as separate explanatory variables explaining technology growth may create unsolvable endogeneity problems. In particular, in order to regress productivity, institutions and human capital altogether within equation (8) we may need to perform a three-stage least squares regression. This can be only done when distinct instruments for the two suspected endogenous variables are found.

Crucially, not only we have to find such instrumental sets but also instruments have to be orthogonal one another and not collinear. The task seems rather difficult and instruments may be very weak precluding the possibility of correctly estimating the basic relation we want to test. Therefore we chose to control for differences in educational levels across countries by using TFP estimates which already account for human capital stocks within the production function as it is usually done in many other empirical works[20].

Another data issue peculiar to our work is concerned with the choice of the index to be used as a proxy for Institutions. The institutional quality estimates we use come from the Economic Freedom index (EFW) elaborated by the Fraser institute (www.fraserinstitute.ca).

"if firms have different markups of price over marginal cost, or pay different wages, then society may value resources differently in different uses. Reallocating resources towards highly valued uses raises aggregate productivity, without necessarily reflecting changes in technology". Hence, under imperfect competition, there is no need to immediately rely on technological change for an explanation of an increase in aggregate measured productivity.

[18] Basu and Fernald (1997) p.7 on U.S. data. Basu and Kimball (1997) p. 16.

[19] We refer the interested reader to Baier, Dwyer and Tamura (2002) for a more detailed description of computation methodology. Some seemingly superior measures of human capital are given by de la Fuente and Doménech (2002). However, the short longitudinal dimension of their dataset (only 21 OECD countries) precludes their use in this context.

[20] Hence, we do not discard the contribution of human capital differences in the process of technology growth. These differences are considered within the estimation of TFP levels while the effects of IQ differences will be on the speed of technology catch up. The estimation of "human capital corrected TFP level" is nowadays almost a standar procedure. See for instance Hall and Jones (1999), Klenow and Rodriguez-Clare (1997), Caselli (2005) only to cite some.

This is a cross-country index of differences in economic freedom. The survey data are from two annual publications: the *Global Competitiveness Report* and the *International Country Risk Guide*.

The index measures the degree of economic freedom with 5-year span intervals in between 1970 and 2000 in five major areas: (i) Size of Government: Expenditures, Taxes, and Enterprises, (ii) Legal Structure and Security of Property Rights, (iii) Access to Sound Money, (iv) Freedom to Trade Internationally and (v) Regulation of Credit, Labor, and Business. Within the five major areas, 21 components are incorporated into the index but many of those components are themselves made up of several sub-components. Counting the various sub components, the EFW index utilizes 38 distinct pieces of data.

This is one of the main advantages[21] of using this index which provides both (i) the overall index of each country's Institutional Quality and (ii) the disaggregated data used to compute it. Hence, it will be possible in what follows to test which of the 5 main areas that compose the EFW are more important in the catch up process and therefore to highlight what particular aspects of the broader IQ index is more willing to play a role in technology flows from leader countries to laggards.

Hence, due to institutional data availability our sample size is of 50 countries for which data are available for the years in between 1970 and 2000[22]. This is a relatively small number of countries. Nonetheless, the 50 countries within our sample sum up to almost 75% of the world GDP in PPP for the years considered. We will also show how the main empirical results are invariant when we enlarge sample size by using the institutional index of Hall and Jones (1999) for which we posses a higher number of countries but which relies on a single year estimate of institutional quality (the year 1988) which proxies for the whole period[23]. We will also show how the results hold when we restrict the sample to a smaller pool of developing countries which more than others may be affected by the process of technology catch-up.

5 The empirical framework

5.1 Empirical model

We use the empirical specification provided by Benhabib and Spiegel (2005) in order to test eq. (8). This is given below in a form which nests both a logistic ($\rho = 1$) and a confined

[21] Another one is that, differently from other indexes, the EFW propose a chain-linked index which is more suitable for cross-country comparison since data are consistent over time in the sense that an estimate of institutional quality for a certain country is provided only if adjacent years are available for the same country and sub-institutional variables. We avoid, this way, to compute averages of institutional quality which rely on different variables' baskets.

[22] All available countries were inserted into the sample for which at least 25 years observation were available for all the main variables. Countries in our sample are: Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Burundi, Canada, Chile, Cyprus, Denmark, Fiji, Finland, France, Germany, Ghana, Greece, Hong Kong, India, Indonesia, Ireland, Israel, Italy, Japan, Jordan, Malawi, Malaysia, Mali, Mauritius, Morocco, Netherlands, Newzealand, Nigeria, Norway, Pakistan, Panama, Peru, Philippines, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland, Tanzania, Thailand, Trinidad, Turkey, United Kingdom, Usa.

[23] The main problem with the index proposed by Hall and Jones (1999), and which is the reason we chose not to use it as main index for our work, is that this does not match the time span we analyzed in our work. However, it may be argued that institutional quality changes over time only slowly and that the analysis ran by using these data still provides a good approximation for the hypothesis we are here testing. Moreover, the EFW index proves to be better than the Social Infrastructure index of Hall and Jones (1999) in the fact that it can be disaggregated into its main sub-components. This feature will be very useful in disentangling the partial effects of different institutional arrangements on technology flows in what will follows.

exponential diffusion of technology ($\rho = -1$):

$$\Delta a_i = b + \left(g + \frac{c}{\rho}\right)\bar{s}_i - \frac{c}{\rho}\bar{s}_i\left(\frac{A_i}{A_l}\right)^{\rho} + \varepsilon_i \tag{14}$$

with $\varepsilon_i \sim i.i.d.N(0,1)$. The subscript i denotes a generic follower country within the set I denoting the whole pool of followers with $i = 2, 3.., F$ and $i \neq l$. Δa_i is the average annual TFP growth rate of country i. The subscript l represents the leader country, that is, the U.S. while $\bar{s}_i$ is the log average institutional endowment of country i.

We also rearrange the catch-up condition in eq.(11) in the empirical fashion proposed by Benhabib and Spiegel (2005). This is given below for the logistic case:

$$S^*_{i,t} = \exp\left(\frac{g\bar{s}_{l,t}}{g + c}\right) \tag{15}$$

where $\bar{s}_{l,t}$represents the log of average institutional quality of the leader. $S^*_{i,t}$ is therefore the threshold level of institutional quality that a country must own in order to theoretically catch-up with the leader. A level of institutional quality lower than the threshold implies, theoretically, divergence from the frontier.

5.2 Endogeneity issues

As briefly pointed out before, endogeneity between economic institutions (EFW) and productivity is likely to arise in our context. Put it in other words, it is going to be difficult to correctly estimate the partial effect of institutional quality on the technology catching up process since the relation between institutions and productivity is likely to be simultaneous and suffer from reverse causality.

We address this problem by making use of appropriate instrumental variables estimation techniques (IV). Our choice of the instrumental set relies on previous empirical work. The institutional quality of a country has been often put in relation with its colonial history. In particular, Hall and Jones (1999) and Acemoglu, Johnson and Robinson (2001) interestingly point out how those regions which have been colonized by European countries are more likely to have developed social infrastructures similar to the motherland. Assuming that European countries have better institutional infrastructures for trade, research and economic growth, we may observe a positive correlation between a country's institutional quality and its linguistic characteristics which proxy for the influence exerted by the motherland.

In particular it is often assumed that the bigger is the fraction of a country's population speaking one of the 6 major European languages (or English) and the higher will be its institutional quality[24]. The latitude of a country, on the other hand, may be providing useful information about the kind of colonialism to which regions have been exposed to. In particular, it is argued that if a country lies on similar latitudes of major European countries (in the range of, let us say, France, England and Spain) this may be a signal of the presence, in those regions, of a "non-predatory" colonialism. To put it in other words, it is more likely that colonialists actually settle down in regions with similar climate conditions as the motherland ultimately bringing with them their home-country institutions. Instead, being located in more isolated regions and with climate conditions very different from the motherland may have resulted in a predatory colonialism which led to the establishment of "*extractive*" institutions.

[24] Hall and Jones (1999) and many others.

Also, the degree of trade openness of a country may help to judge the goodness of a country's IQ as long as this instrument is proven to be orthogonal to the error process in the regression. Usually, empirical works use a measure of trade openness coming from gravity equations. Here, instead we use the measure of trade openness coming from the work of Sachs and Warner (1995) which we will prove to be strongly orthogonal to the error process and therefore truly exogenous[25].

5.3 Regression results

The above mentioned instruments, that is, the fraction of population speaking English or another European language, latitude and openness to trade as measured by Sachs and Warner (1995) are used in the IV estimation of eq.(14). We initially choose to estimate the logistic diffusion process of technology by imposing (rather than estimating) the coefficient $\rho = 1$. We give the results in table 2.

Table 2: IV estimates of eq. (14)

Logistic diffusion function

Dependent Variable: Annual TFP growth 1970-2000			
			β -convergence
Constant	*-0.108*	*-0.142*	*-0.012*
	*(0.028)****	*(0.042)****	*(0.025)*
$\ln(\bar{S}_{1970-2000})$	*0.070*	*0.056*	*0.046*
	*(0.021)****	*(0.016)****	*(0.013)****
$\ln(\bar{S}_{1970-2000})$ **TFP gap*	*-0.014*	*-0.031*	
	*(0.007)***	*(0.009)****	
Set of controls			
Ln Ypp 1970		*0.010*	*-0.005*
		*(0.003)****	*(0.002)****
Ln invest.Rate 1970		*0.003*	*0.012*
		(0.004)	*(0.004)****
Un-Centered R2	*0.36*		
Over-ID	*Accepted*		
F-test of excluded instruments	*12.44*		
Shea partial R2	*0.53*		
D-W-H endogeneity test	*3.72*		
p-value	*(0.05)*		
Wu-Hausman stat.	*3.70*		
	(0.06)		
H0: Exogeneity			
Pagan-Hall Heterosk. Test	*29.75*		
p-value	*(0.07)*		
n. Obs	*50*	*50*	*50*

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

$\ln(\bar{S}_{1970-2000})$ *represents log of average institutional quality over the period 1970-2000.*

TFP gap represents the ratio of each country's TFP initial level to U.S as TFPi/TFPm

Instruments: (i)Fraction of population speaking English (ii) Fraction of population speaking one of the 6 major European languages, (iii) Latitude, (iv) Years open to Trade as specified in the text.

Coefficients enter with the expected sign and are all econometrically robust at 1 percent confidence levels confirming how institutional quality seems to act as an enhancing factor

[25] One may be skeptical about the true exogeneity of this instrument. However, we perform a C-test checking its exogeneity finding this instrument to be strongly orthogonal in the IV regression with a p-value of .95.

in the flows of technology from the leader to the followers. Also, the positive and statistical coefficient on the variable capturing institutional quality alone, namely $g(S_i)$, points to the fact that, as we expected, a higher institutional quality is a fundamental variable for economic growth *per sè* even outside the context of technological catch-up.

The main result shows how, holding constant the distance from the frontier, those countries endowed with better institutions are, on average, catching up faster with the leader by means of positive (and higher) TFP growth rates.

Instruments here used are strongly exogenous leading to the acceptance of the over-ID test on the instrumental set while, differently from what suspected, we cannot reject the hypothesis of exogeneity of institutional quality at 10% confidence levels. This comes somehow as a surprise. However, the fact that institutional indexes are only a proxy of real institutions leads us to be careful in accepting the true exogeneity of the regressor. In particular, as pointed out by Hall and Jones (1999), IV estimation may be of help in solving both endogeneity and measurement error problems so that we prefer to stick to the IV estimation results rather than a simpler OLS. From an econometric point of view, due to the presence of heteroskedasticity signaled by the Pagan-Hall test we make use of heteroskedasticity robust standard error estimates.

5.4 Some robustness checks

To the initial specification we add some control variables which are commonly used in growth regression in order to capture β-type convergence mechanisms. These are the log of GDP per capita in PPP and the investment rate in the initial year. Only the first is found to be statistically significant. Of particular interest is the sign of the coefficient on the initial GDP level which, rather than being negative as expected it is, instead, positive.

This seems to point to the fact that much of the empirically observed β-convergence may be actually driven by catching-up in productivity levels across countries. Results are shown in the last column of table 2. Noticeably, in fact, once we control for the productivity catching-up term in our main regression, the positive coefficient on initial GDP implies that countries which are richer tend to grow faster than others. Instead, when we run a traditional β-convergence regression, that is without inserting the technology catching-up term, we obtain the expected negative coefficient on initial GDP level. This shows the same strong statistical significance of the, instead positive, coefficient obtained when we also insert the TFP catching-up term. The logical intuition we get from this result is that the β-convergence may be mainly due to convergence and catch-up of followers' technological levels to those of the leader.

As an additional robustness check we test also the confined exponential specification of technology diffusion by imposing $\rho = -1$[26]. The results are given in table 3.

[26] Differently from the logistic formulation, here the larger the technology gap and the higher the potential for rapid growth independently from the fact that distant technologies may be more difficult to be adopted. This is actually the same formulation used in Barro and Sala-i-Martin (1997).

Table 3: IV estimates of eq. (14)

Confined exponential diffusion function

Dependent Variable: Annual TFP growth 1970-2000		
Constant	-0.09 (0.018)***	-0.05 (0.031)**
$\ln(\bar{S}_{1970-2000})$	0.050 (0.009)***	0.038 (0.013)***
$\ln(\bar{S}_{1970-2000})$ *TFP gap*	0.002 (0.001)***	0.003 (0.002)**
Set of controls		
Ln Ypp 1970		-0.000 (0.00)
Ln invest.Rate 1970		0.010 (0.004)***
Un-Centered R2	0.35	
Over-ID	accepted	
F-test of excluded instruments	22.58	
Shea partial R2	0.67	
D-W-H endogeneity test p-value	4.23 (0.04)	
Wu-Hausman stat.	4.25 (0.04)	
H0: Exogeneity		
Pagan-Hall Heterosk. Test p-value	26.91 (0.14)	
n. Obs	50	50

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

$\ln(\bar{S}_{1970-2000})$ *represents log of average institutional quality over the period 1970-2000.*

TFP gap represents the ratio of each country's TFP initial level to U.S as TFPi/TFPm.
In the confined exponential diffusion function the TFP gap is $(TFPi/TFPm)^{-1}$ *as in the text.*

Instruments: (i)Fraction of population speaking English (ii) Fraction of population speaking one of the 6 major European languages, (iii) Latitude, (iv) Years open to Trade as specified in the text.

Again coefficients are statistically significant at 1 percent confidence intervals. The coefficient associated to the term $\ln \bar{S}_{1970-200} * (TFP_i/TFP_l)^{\rho}$ enters with a positive sign, as expected. That is, the larger the technological gaps from the frontier and the higher TFP growth rates will be. The flow of technology from leader to follower is again mediated by country specific institutional quality. That is, a country exploits its potential for high growth in the presence of good institutional infrastructures which allows it to adopt leading-edge technologies faster.

We run some other robustness tests on the results obtained so far by using different measures of institutional quality. We use both the indexes proposed by Hall and Jones (1999), (i) "social infrastructures" and (ii) its sub-index called GADP (Government Anti-Diversion Policies). The correlation between the EFW index and these other two measures is high but not perfect. Hence, we believe, their use may be of help in assessing the robustness of our results in the presence of different measures of institutional quality. Even though sample size increases quite considerably the main results hold with very strong statistical significance[27]. This is shown in table 4.

[27] Moreover, the use of the Hall and Jones' indexes required to use a different instrument (the log of Frankel and Romer trade predicted share) in order to avoid multicollinearity with regressors.

Table 4: IV estimates of eq. (14)
on Social Infrastructure and GADP indexes
Logistic diffusion function

Dependent Variable: Annual TFP growth 1970-2000		
	(i)	***(ii)***
Constant	*-0.04* *(0.009)****	*-0.08* *(0.017)****
Ln Social Infrastr.	*0.031* *(0.08)****	
*Ln Social Infrastr.*TFP gap*	*-0.012* *(0.003)****	
Ln GADP		*0.048* *(0.011)****
*Ln GADP*TFP gap*		*-0.01* *(0.002)****
Un-Centered R2	*0.48*	*0.48*
Over-ID	*Accepted*	*Accepted*
F-test of excluded instruments	*4.47*	*5.33*
Shea partial R2	*0.16*	*0.19*
D-W-H endogeneity test	*0.63*	*1.28*
p-value	*(0.42)*	*(0.25)*
Wu-Hausman stat.	*0.61* *(0.43)*	*1.24* *(0.26)*
Pagan-Hall Heterosk. Test	*21.24*	*21.69*
p-value	*(0.39)*	*(0.36)*
n. Obs	*97*	*97*

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

Social Infrastructures and GADP (Government Anti-Diversion Policy) indexes are taken from Hall and Jones (1999).
TFP gap represents the ratio of each country's TFP initial level to U.S as TFPi/TFPm

Instruments: (i)Fraction of population speaking English (ii) Fraction of population speaking one of the 6 major European languages, (iii) Latitude, (iv) Years open to Trade as specified in the text.

5.5 Institutional threshold analysis

We showed how, in the fashion of Benhabib and Spiegel (2005) it is possible, within the logistic diffusion function, to compute some minimum institutional level below which followers will not theoretically catch-up with the frontier accordingly to the model.

Our point estimates for the logistic diffusion of technology given in figure 1 imply an insitutional threshold value of 5.18 (on a scale from 0 to 10 with the U.S. scoring 7.8). That is, those countries with an average institutional quality below 0.66% w.r.t. the leader will theoretically fall behind without catching up. Out of the 50 countries examined 15 experience an institutional level lower than the estimated threshold. These are Ghana, Nigeria, Bangladesh, Brazil, Tanzania, Burundi, Malawi, Peru, Turkey, Argentina, Israel ,Pakistan, India Mali and Morocco. Out of these, only Turkey, Israel and India experience a positive TFP growth while the others, experiencing negative productivity growth, are clearly diverging from the leader confirming the goodness of the theoretical model.

The distance from the threshold experienced by Argentina, India, Israel and Turkey is however small. This points to the fact that with even moderate institutional improvements these countries may invert their diverging patterns. For the other countries, instead, major improvements in institutional quality seem to be required in order to be pushed out from a self locking divergence club. The overall picture, nonetheless, seems to point to cross-country convergence and catch up with some cases of self locked diverging countries.

6 Extensions of the model

6.1 The effects of different policy arrangements on productivity growth

Up to now we provided some empirical evidence of the positive impact of institutional quality on productivity growth. The effect of sound institutional frameworks seem to work on two separate channels. On one hand, having higher institutional quality fosters TFP growth *per se* by ensuring the adequate economic environment conductive to higher productivity growth and technology growth by innovation.

On the other hand better institutions enhance the transmission of technology from the leaders to the followers. Empirical tests seem to show how followers with good institutional frameworks are those experiencing a faster rate of technology catch-up on the average. Also, in our setting, countries lacking a critical value of institutional quality may be theoretically unable to catch-up with the leader. We proved how this hypothesis has empirical grounds, with those countries below the model implied institutional threshold decreasing on their productivity performances over the examined period and ultimately diverging from the technological frontier.

From a policy making point of view, however, we may be interested in deepening the analysis trying to discern which are the best policies and institutional arrangements for technology diffusion and catch-up across countries.

The overall institutional quality of a country is given by the sum and interaction of many policy arrangements (or institutional sub-categories). In the case of the EFW index, for instance, these are given by 5 main sub-components: (1) Size of Government: Expenditures, Taxes, and Enterprises, (2) Legal Structure and Security of Property Rights, (3) Access to Sound Money, (4) Freedom to Trade Internationally and (5) Regulation of Credit, Labor, and Business.

Even tough all of these sub-categories are important in defining the overall level of a country's institutional quality, only some of them will, however, prove to be specifically crucial for the productivity catch-up process of an economy.

6.2 Disaggregating institutions

In this section we attempt to analyze the impact of different policy arrangements on both the innovative and the technology catching-up process across countries. We do so by disaggregating the EFW index into its main components and using each component as a separate proxy for a different institutional arrangement.

A first basic problem when trying to analyze specific policies or institutional arrangements relies on the fact that the same variable usually does not have a univocal impact on countries which differ in their fundamentals. A certain policy, for example, may not impact the leaders and the followers the same way or with the same intensity.

A recent strand of literature develop the idea that certain institutions which foster economic growth in developed countries may actually hinder the growth of least-developed ones. Acemoglu, Aghion and Zilibotti (2006), Aghion, Harris, Howitt and Vickers (1997), Aghion et al. (2005) or Aghion and Howitt (2005), for instance, build on the seminal work of Gerschenkron (1962) by assuming that countries lagging behind the technological frontier, and that perform technology imitation, may be better off by some non-competitive policies in the early stages of their development

Additionally, a defined policy may lead to different results when its effects are studied over the innovative or the "imitative" activities within the same country as well[28]. Productivity growth in leader countries, for example, may be mostly (or completely) driven by innovation processes while the opposite may be true for countries lagging behind. Different policies, therefore, are likely to impact differently countries which do not share the same economic background, development levels or fundamentals.

Our aim is, however, to detect which are the institutional arrangements specifically enhancing the process of technology catch-up across countries and particularly affecting follower countries. For this reason, along with the analysis carried out over the whole sample, we will also isolate the group of countries which we believe to represent technological followers and test the impact of different institutional arrangements on these countries in order to obtain more precise insights about the determinants of faster technology adoption versus technology creation.

The definition of the group of followers and leaders is not, however, a straightforward task. We chose to depart from already established group definitions, such as for example the dichotomy OECD (or developed) versus non OECD (or developing) countries, due to the peculiarity of the process of technology transfer and adoption. From the point of view of technology adoption and transfer, in fact, it may be argued that many of the developed countries are heavier imitators than some developing ones since they have the technical capabilities to reverse engineering their competitors' products. On the other hand many developing countries, even though potential imitators, may not exploit their relative backwardness advantage due to the lack of minimun technical skills apt to imitate or adopt technologies at the frontier.

Hence, we choose to define the group of followers by a measure of the distance from the technological frontier in order to avoid *a priori* sample grouping biases. Here we consider as "followers" all the countries for which a technological gap from the U.S. is of 10% or more in the initial year. This leads to a group of 35 followers and 15 leaders.

We test a slight modification of eq.(14) firstly on the "ALL" sample and then on the group of "Followers" as follows:

$$\Delta a_i = b + \left(g + \frac{c}{\rho}\right)\bar{s}_i - \frac{c}{\rho} Z_i' \left(\frac{A_i}{A_l}\right)^{\rho} + \varepsilon_i \qquad (16)$$

where $Z_i^{'}$ represents a vector of the 5 countries' specific institutional sub-indexes taken in logs. We give the results in figure 4 at the bottom of the paper.

As expected, overall institutional quality is again statistically significant in explaining cross-country productivity growth rates differentials. Additionally, as suspected, some of the institutional sub-components do not seem to explain the technology catching-up process. In particular, the results show how cross-country differences in (1) Size of Government: Expenditures, Taxes, and Enterprises, and (5) Regulation of Credit, Labor, and Business never enter the regressions with significant coefficients for whichever model specification and

[28] Notice, in fact, that up to now we assumed the economies to both innovate and imitate. The innovative activity of a country is taken to be a function of its specific institutional quality level (the first term in eq.(8). Instead, the imitative activity is a function of the experienced technology gap and of its interaction with institutional quality (second term in eq.(8)).

that, therefore, seem to be of negligible importance in explaining differences in technology flows across countries.

Interestingly, our empirical investigation points to three major institutional arrangements as being fundamental in the process of technology cacth-up across countries. These are (i) " Legal Structure and Security of Property Rights"[29], (ii) "Freedom to trade internationally"[30] and (iii) " Access to sound money"[31]. However, as expected, the strenght and the signs of the coefficients of these variables is sometimes different when we focus on the whole sample or on the reduced group of followers.

The strongest result is shown by the variable proxying for Legal Structure and Security of Property Rights. Once we control for the overall IQ of a country, a tightening of property rights and of the legal strucutre of the economy seems to reduce the speed of technology adoption. The coefficient for the variable capturing the interaction between the distance from the technology frontier and the enforcement of property rights enters with a positive sign (in the logistic formulation meaning a negative elasticity on TFP growth). This coefficient is estimated to be statistically significant at 1 percent confidence levels. Our point estimates show how, *ceteris paribus*, an increase of 1 percent in the enforcement of property rights, as measured in the EFW index, will reduce the rate of technology adoption by a value in between 2 percent (for the whole sample) and 4 percent (for the followers' group).

[29] This index is an average of: (i) Judicial independence, (ii) Impartial courts, (iii) Protection of intellectual property rights, (iv) Military interference in the rule of law, (v) Integrity of legal system (rule of law) which are all expected to control for the extent to which property rights are ensured within an economy.

[30] This index is an average of 5 minor sub-categories: (i) Taxes on international trade, (ii) Regulatory trade barriers, (iii) Actual size of trade sector compared to expected size, (iv) Difference between official exchange rate and black market rate, (v) International capital market controls.

[31] This index is an average of: (i) Average annual growth of money supply, (ii) Standard inflation variability during last five years, (iii) Recent inflation rate, (iv) Freedom to own foreign currency bank accounts domestically and abroad.

Table 5: IV estimates of eq. (16) on "All" and "Followers" sample

Logistic diffusion function

Dependent Variable: Annual TFP growth 1970-2000	ALL	ALL	Followers	Followers
Constant	-0.098 (0.021)***	-.113 (.027)***	-0.111 (0.29)***	-.101 (.025)***
$\ln(\bar{S}_{1970-2000})$	0.066 (0.014)***	.073 (.020)***	0.070 (0.02)***	.064 (.020)***
*Ln Size of Govt.*TFP gap*	-0.002 (0.007)		0.014 (0.01)	
*Ln Property Rights*TFP gap*	0.034 (0.011)***	.022 (.007)***	0.049 (0.014)***	.041 (.011)***
*Ln Inflation and money*TFP gap*	-0.026 (0.010)***	-.034 (.010)***	-0.014 (0.013)	
*Ln Trade Openness*TFP gap*	-0.002 (0.014)		-0.052 (0.023)***	-.050 (.015)***
*Ln Business- labour Reg *TFP gap*	-0.020 (0.018)		-0.004 (0.033)	
Un-Centered R2	0.52	0.45	0.61	0.56
Over-ID	Accepted	Accepted	Accepted	Accepted
F-test of excluded instruments	9.66	11.69	4.09	12.07#
Shea partial R2	0.49	0.52	0.39	0.55
D-W-H endogeneity test *p-value*	2.04 (0.15)	2.81 (0.09)	0.65 (0.42)	1.31 (0.25)
Wu-Hausman stat. *p-value*	1.79 (0.18)	2.68 (0.10)	0.51 (0.48)	1.17 (0.28)
Pagan-Hall Heterosk. Test *p-value*	36.85 (0.96)	28.74 (0.37)	25.81 (0.99)	20.52 (0.42)
n. Obs	50	50	35	35

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

$\ln(\bar{S}_{1970-2000})$ *represents log of average institutional quality over the period 1970-2000.*

TFP gap represents the ratio of each country's TFP initial level to U.S as TFPi/TFPm

Instruments: (i)Fraction of population speaking English (ii) Fraction of population speaking one of the 6 major European languages, (iii) Latitude, (iv) Years open to Trade as specified in the text. #Latitude has been eliminated from the instrumental set since not truly orthogonal to the error process.

From a theoretical point of view there are reason to believe that an enforcement of property rights may have mixed and ambigous results on the growth of productivity of a country. In a well known paper Helpman (1993) shows, for example, how enforcing IPRs and strenghtening the legal structure of an economy in different regions of the world (the North and the South where, respectively innovation or imitation is performed) may lead to ambiguous welfare results. Least developed countries usually own a comparative advantage in the manufacturing sector due to low wages. If property rights (in particular IPRs) are lax enough these countries may be actually able to compete in product markets by imitating technologies discovered elsewhere reaping off the costs of innovation. On the other hand, a tightening of IPRs in follower countries may lead northern regions to exert their monopoly power which would be detrimental to southern regions.

Hence, Helpman (1993) show how also northern regions may be worse off by a tightening of IPRs due to a reduction of the long-run effort in the innovative sector[32] and to a less efficient interregional allocation of production.

[32] See Helpman (1993), propositions 1 and 2.

This result is on the same line as that of Kwan and Lai (2003) , Grossman and Lai (2004) and Connolly and Valderrama (2005) who argue how, when the transmission of technology works through the imitation channel, an increase in the protection of intellectual property rights may end up reducing the speed of technology adoption. *Ceteris paribus* within the same economy, the enforcement of IPRs implies a trade-off between the positive incentive given to the R&D sector and the negative effect coming from an increase in the cost of imitation.

Hence, if on one hand, increasing the protection of IPRs theoretically ensures the innovators to be rewarded for the investment in R&D, on the other hand strenghtening IPRs protection significantly rises the costs of imitation. Levin et al. (1988) and Gallini (1992) argue how argue how "*patents raise imitation costs by about forty percentage points for both major and typical new drugs, by about thirty precentage points for major new chemical products, and by twenty-five percentage points for typical chemical products*".

As pointed out by Connolly and Valderrama (2005) a similar trade-off exists, on a cross-country basis, between developed countries (the innovators) and developing ones (the imitators). Developed countries, where virtually all the innovation is performed, have pushed strongly for international enforcement of IPRs while many of the developing countries have been opposing this scenario by arguing how too tight IPRs may end up slowing down economic growth and harming their development by reducing drastically their access to new technologies.

The ambiguity of the effect of a tightening of property rights on the growth of developing countries finds empirical grounds in our results. It is interesting to notice, in fact, how in our setting a tightening of property rights actually works in two directions. A stronger protection of property rights not only reduces the rate of technology adoption but, at the same time, it increases the overall quality of a country's IQ[33]. This is shown to foster the innovative activity of an economy with the positive and significant coefficient associated to the overall index of institutional quality in table 5 above. It can be argued, therefore, that the overall effect will depend very much on the weight of the innovative sector w.r.t. the imitative one in the particular country under consideration, that is, on whether the country is an innovator, an imitator or both.

Countries closer to the technological frontier will be less harmed by the enforcement of property rights than their follower counterparts and *viceversa*. Rephrasing Maskus (2000) we may affirm that "*national regimes of intellectual property rights depend on the level of economic development*", but also that this relation is simultaneous in the sense that the effects of a tightening of IPRs will be dependent on the development stage of the country taken into consideration. One may argue how least-developed countries devote very little resources to protection of intellectual property rights due to the the innovative effort in these countries is very low. In this situation economic and political interests usually opt for weak protection of IPRs. As income and technical capabilities raise at higher development stages, the impact of tighter IPRs become less and less detrimental since demand shifts towards higher-quality products and the innovative activity becomes predominant.

[33] Unfortunately, due to the fact that only 4 instruments are available to proxy for institutional quality we are not able to estimate the "direct" impact of each institutional arrangement on TFP growth and, at the same time, correctly solving for the endogeneity between this variables. Instead, we can only solve for the endogeneity problem when considering the overall effect of EFW on TFP directly. Only then we are able to disentangle the partial effect of each institutional subcategory on the process of TFP catch-up alone. Hence, the result should be regarded as answering the following question: "once accounted for differences in overall IQ across countries, what are the institutional arrangements which more than others foster technology catch-up?".

From an econometric point of view an additional problem arised with the estimates for the subsample of followers. As Staiger and Stock (1997) and others argued, a problem of "instrument-weakness" can arise even in the context of "first stage tests" which seem to be satisfactory under the conventional significance levels (5% or even 1%) but whose F-test is below the value of 10. Staiger and Stock (1997) show how, in presence of a single endogenous regressor the two stage least squares estimates and conventional confidence intervals are unreliable. This is the case for the IV estimation in the third column of table 5.

Hence we decided to check for the true orthogonality of the instruments in our set in order to verify whether the low score of the F-test in the first stage regression may be actually imputed to a weak instrument within the instrumental set when running the regression for the followers group. A way to deal with this possibility is to test for a subset of orthogonality conditions by using what is called the "difference-in-Sargan" statistic or C-test.

This statistic is computed as the difference between a restricted and an unrestricted Sargan test for the IV estimate (or J-statistics for the GMM). The unrestricted Sargan uses the full set of instruments while the restricted one only uses a smaller set of true orthogonality conditions. The idea behind this test is that, if the inclusion of a suspect instrument (or of a subset of instruments) into the unrestricted regression leads to a significant increase in the value of the J-stat or of the Sargan test, then this is a good reason to doubt about the true exogeneity of the added instrument. We apply the C-test to all four instruments in our set disjointly. Our estimates for the C-test show how the instrument "latitude" is not actually orthogonal to the error process and therefore should be eliminated from the first stage regression for the subsample of followers. Once we do it the resulting F-test jumps from a value of 4.09 to the acceptable 9.45. When we also exclude from the regression the non significant explicatory institutional variables the F-test scores a value of 12.07.

Going back to the results in table 5, a positive impact over the TFP catching-up process is shown by the variable "Access to sound money" which proxies for Inflation controls and sound macroeconomic framework. The economic intuition behind our result relies on the fact that high and unpredictable inflation rates drastically rise the risks of doing business. Additionally, internal and external trade are significantly hampered. From a technology catching-up perspective, the costs of high inflation levels on productivity flows from leaders to followers might negatively work through the reduction of FDI and internal investments in those countries experiencing inflation crisis. This result is highlighted by many empirical works such as Fischer (1993), Levine and Renelt (1992) or Rogoff and Reinhart (2003). This result is stronger for the whole sample specification while it is not significant for the group of followers.

Finally, "Freedom to trade internationally" and all the policy arrangements which enhance trade openness are shown by our empirical investigation to be beneficial for economic growth and productivity catch-up. The coefficient for the variable capturing trade openness is significant for the group of followers in our sample. As pointed out, for instance, by Alcalà and Ciccone (2004) or Dollar and Kraay (2003) there exists a positive relationship between good institutions, openness to trade and growth[34]. Hence, from the perspective of technology catching-up analysis, the positive effect of trade on the growth of productivity is expected to be especially true for follower countries since opening up to trade may allow

[34] Countries that trade more are those which more benefit from technological spillovers and therefore tend to grow faster than others ultimately being more productive. This result holds both for the innovative and imitative sectors.

some significant reverse engineering and faster technology imitation[35]. Also the work of Sachs and Warner (1995) shows how open, but still developing, countries are found to grow by 4.5% per year in the 1970s and 1980s, that is, 4 percentage points more than their closed counterparts. Our empirical results seem to confirm this hypothesis and be consistend with previous empirical results.

7 Conclusions

The paper addressed the issue of technological catching-up across countries by focusing on the role of institutional quality. Differences in institutional quality across countries are found to be of crucial importance in explaining differences in technology flows from leaders to followers. Empirical estimates show how institutional quality acts as an enhancing factor for technology transfers from the world frontier to the laggards allowing the latters to theoretically catch-up with the leaders. Instead, countries lagging behind the technological level of the leader and, at the same time, owing poor institutions are showed to experience very low GDP and productivity growth rates.

We showed how, by assuming technologies to be "development-stage specific" some more restrictive catching-up conditions arise. In particular, we assumed a logistic functional form in order to model the technology diffusion process. In that, very far technologies are more difficult to be adopted because the technology gap between the frontier and the recipient country is very high. Hence, we re-adapt Benhabib and Spiegel (2005) framework so as to define some minimum institutional level below which followers do not theoretically catch-up. Out of the 50 countries examined, 15 experience an institutional level below the theoretical insitutional threshold. These are also the countries actually experiencing a decline in productivity over the period and therefore diverging from the frontier.

Institutional quality is not only found to be of importance in determining technology transfer from the leader to the follower. Also, having good institutional quality acts as a promoting factor for the technological innovation of an economy *per se*. This result has already been established by a variety of models and empirical works where TFP growth rates are found to be highly correlated to good institutions.

We observe evidence of β-convergence in our sample. This, noticeably, seems to be driven by the process of technology catch up highlighted in our framework. In particular, when we account for possibility of technology catch up, the negative coefficient associated to the initial levels of GDP changes its sign to positive implying a fundamental role of technology catch up within the β-convergence process.

Starting from these results we had been looking at the issue more deeply by assessing what the particular institutional arrangements boosting the innovative activities of a country are and what, instead, are those which more pertain to the imitation mechanisms within the same economy. We disaggregated the broad index of instititutional quality into its main subcategories and ran a TFP catching-up regression trying to disentangle the partial effect of each specific institutional arrangement on the process of technology adoption and growth.

[35] We claim that the positive impact of trade on productivity growth may especially true for developing countries due to the fact that usually this result holds in very large samples where the share of developing countries over developed ones is very high. Also, Alcalà and Ciccone (2002) show how trade and institutional quality have a positive and statistically robust impact on GDP growth when the sample is restricted to former colonies (which are usually developing countries). With the same result the work of Dollar (1992) for a sample of 95 LDCs.

Theoretical literature points to openness to trade, enforcement of property rights and sound macroeconomic policies, such as controls to inflation and monetary policies, as important policy arrangements for both technological activity and investments conductive to productivity growth. However, as highlited by recent literature such as Acemoglu, Aghion and Zilibotti (2006) or Aghion and Howitt (2005), some institutional arrangements which may be growth enhancing in developed countries may be growth detrimental for least developed ones. We found confirmation of this hypothesis in our empirical examination. In fact the overall growth effects of the institutional subcomponents we used seem to be ambigous if examined simultaneously across the innovative and the imitative sector of an economy or, also, on a cross-country basis when countries are divided into leaders and followers.

Trade-oriented policies and enforcement of property rights, whose effect is captured over the innovative and imitative sectors of the economies under consideration, are found to be the most significant variables explaining faster technology flows from the frontier to the follower countries. We found that an increase in trade openness is beneficial both for the innovative and imitative activities of leaders and followers. The positive impact on TFP growth of trade works on two separate channnels. The first is directly by increasing the index of institutional quality which itself positively impacts TFP growth rates. The second is through the positive effect on the rate of technology adoption in follower countries which, when more open, are found to catch-up faster with the technological level of the leader.

A tightening of property rights, instead, works in different directions. Enforcing property rights boosts the innovative activity by raising overall institutional quality and raising TFP growth rates. However, when property rights are tightened followers find more difficult to imitate technologies discovered elsewhere due to a likely relative increase in the costs of imitation. Hence, empirical investigation show how the rate at which new technologies are adopted decreases with a consequent decrease in TFP growth rates when IPRs are robustly enforced. The overall effect is mixed and its sign is expected to depend on the particular weight of the innovative versus the imitative sector of the specific economy under consideration, that is, on the development stage of the country taken into consideration.

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