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International spillovers in a world of technology clubs*

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Abstract

Technology is a key element for long-term growth and economic development. Given the stark concentration of innovation activities in a few countries most countries have to rely on the international diffusion newly developed technologies. Some countries may fail to successfully perform the task of technology adaption leading to a tripartite segmentation of countries into an innovation club, an imitation club whose members are capable of absorbing technologies developed by the former and a stagnation group that lack the capability to absorb foreign technologies. We test the technology club hypothesis within a Benhabib-Spiegel type growth regression framework that includes a catch-up variable which is created by interacting human capital with the productivity gap. Using human capital as the threshold variable the estimation procedure identifies two distinct thresholds giving raise to three country groupings. As suggested by the theory of technology clubs we find the strongest effects from the catch-up term on economic growth for the intermediate group (imitation club) and the lowest for the group with lowest levels of human capital (stagnation club).

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1 Introduction

Technology is a key component of long-term growth and successful economic development. In an international context this implies that countries' economic growth does not only depend on domestic technological progress but also on technological developments abroad. If one assumes that technological progress – be it by way of *(i)* innovation or *(ii)* by imitation of existing foreign technologies – is a costly process, not all countries will grow at the same rate. Therefore the level of technology (and hence productivity) differs greatly across countries, a fact which is hardly disputed.

One of the objectives in this paper is to use technology and human capital related indicators to classify countries according to their technological capacity. A country's technological capacity, in a broad sense, depends on both its capability to undertake research and development (R&D) and innovate and its ability to absorb foreign technologies that have been developed abroad. R&D and imitation represent two distinct activities that both feed into technological progress. While innovations add to the existing (global) technology stock and shifts the (global) technological frontier outward, imitation is the process of being able to make productive use of existing innovations. The ability to imitate and adopt foreign technologies for local use must be assumed to be a highly human capital and knowledge intensive process (as are original innovation and R&D). For this reason we follow Nelson and Phelps (1966) in assuming that the capacity to benefit from foreign technologies via international spillovers depends primarily on the level of human capital available in the country. Hence, while it is true that countries with low levels of productivity have a high potential for receiving technology spillovers, de facto, they may find it hard to benefit from such spillovers because of the lack of human resources required for the imitation process. In this case Gershenkron's famous "advantage to backwardness" is counteracted by a lack of absorptive capacity.

Countries will perform neither innovation nor imitation activities if their levels of human capital do not meet the required threshold to undertake R&D and/or imitate foreign technologies. For example, R&D and patenting are highly concentrated activities with the EU, the US and Japan alone accounting for more than two thirds of the global expenditure on R&D in 2007 while the Sub-Saharan countries undertake very little R&D, a mere 0.5% of global R&D expenditures (UNESCO, 2010).

Countries undertaking either innovation, imitation or none may diverge on different growth paths and/or end up at different income levels. This constellation gives raise to the notion of convergence clubs suggesting a tripartite world consisting of an "innovation group", an "imitation group" and "stagnation group". The innovation group includes countries that perform R&D and innovate thereby pushing the global technological frontier outward. Countries in the imitation group do not undertake R&D themselves but take on new technologies developed abroad through absorption of foreign technologies. The stagnation group has insufficient endowments of human capital and skills in order to adopt and implement new foreign technologies. Therefore the countries in this group have very high technology gaps, that is, the difference in their productivity level to the country with the highest productivity.

As pointed out above we will use technology (R&D expenditure) and human capital related variables (literacy rate, years of schooling) for clustering countries into technology clubs. As it turns out, we find three rather distinct clubs which fit well the idea of innovation, imitation and stagnation groups. We then analyse how the members of the three technology clubs are distributed across the 19 world regions defined in the CAM model. We also relate these finding to the scenarios, pointing out that some of the world regions do not have a single member that belongs to the innovation club.

In the second part of the paper, we test whether we can detect catch-up effects - that is growth effects from an existing technology gap – in a growth regression framework and to what extent these catch-up effects are associated with a country's absorptive capacity. Our simple growth equation contains, next to the traditional factors of production, a catch-up variable which – following the work by Benhabib and Spiegel (2005) – is constructed as the interaction of the technology gap and human capital. The latter serves as proxy for countries' absorptive capacity.

We employ the threshold regression approach developed by Hansen (2000) to allow for non-linearities in the catch-up effects of countries, splitting the sample along the human capital dimension. We find that for countries with intermediate levels of human capital there is a large catch-up effect, i.e. countries can to some extent translate their technology gap into higher growth. In our framework we associate the growths effect from the catch-up variable with international technology spillovers. At the same time such a catch-up process cannot be taken for granted as countries with very low levels of human capital enjoy only limited growth effects from their technology gaps – though their technology gaps tends to be large. For the Augur scenarios this implies that in all scenarios that foresee a catch-up or convergence process for the low income regions it should be very well stated by what means their transition to higher income levels is initiated.

The paper proceeds as follows: Section 2 discusses some of the related literature. Section 3 gives the data sources used in sections 4 and 5 which contain the results of our cluster analysis and the growth regressions respectively. In section 6 we relate the findings of the paper to the Augur scenarios. Section 7 concludes.

2 Related literature

The conceptual background for this paper is the endogenous growth literature. Endogenous growth literature explicitly models the law of motion for technology and productivity instead of assuming it to be an exogenous process.

In the model by Aghion and Howitt (1992) firms push the technological frontier by investing in R&D. Firms which come up with a successful innovation gain a temporary monopoly for the production of goods that lasts until it is replaced by the next innovator. Other firms (which are also potential innovators) can build on the innovative contributions of previous innovators so that each new innovation pushes out the technological frontier. Howitt (2000) provides a multi-country version of the Aghion-Howitt growth model. In this model, R&D performing countries with lower productivity will grow at the same pace as the leading country though it will not catch-up in terms of per capita income. The mechanism that ensures the growth convergence is that if a firm innovates successfully, it brings the sectors productivity up the *global* technological frontier. However, not all countries necessarily perform R&D so that some countries will not innovate at all and therefore stagnate giving rise to club convergence (in growth rates).

In an extension of the Howitt (2000) growth model Howitt and Mayer-Foulkes (2005) develop a model with two types of technological advances: *(i)* R&D activity leading to innovations and *(ii)* imitation which is the process of implementing existing foreign technologies. Both innovation and imitation are skill intensive activities. In the convergence club model of Howitt and Foulkes (2005) – which is our main theoretical reference model – countries select themselves into three groups, depending on their technological capabilities. A group of technologically advanced countries will perform R&D and come up with new innovations. This innovation club pushes the global technological frontier. A second group of countries, the imitation club, is successful in imitating and adapting existing technologies previously developed by the innovation group. In contrast, their level of productivity and human capital does not allow them to undertake original R&D. The imitation group successfully implements existing technologies because they have the required level of absorptive capacity which in turn depends on human capital. Here the idea developed by Nelson and Phelps (1966) that countries can benefit from their technology gap vis-à-vis leading countries because it enables them to strongly draw on the existing technology (or knowledge) stock. As in several related models, the imitators and the R&D leaders converge to the same growth path but the former will not succeed in catching-up in terms of per-capita income (compare e.g. Acemoglu and Ventura, 2002; Howitt 2000).

Finally, there is a third group, the stagnation club, which consists of initially backward countries whose low levels of absorptive capacity prevent them from catching-up with the continuously expanding global technological frontier.

These backward countries are trapped in a zero growth equilibrium and will fall behind.

The idea of convergence clubs is also related to the concept of poverty traps (see e.g. Azariadis and Drazen, 1990; Azariadis, 1996) through the high importance attributed to initial conditions and threshold effects. In the poverty trap literature diverging growth regimes are the result of threshold externalities in accumulative factors (Azariadis and Drazen, 1990). A country may be trapped in a low growth, low income equilibrium for several reasons including demography, impatience, institutions (corruption), globalisation or technology (see Azariadis, 1996). The convergence clubs literature also relies on threshold effects that lead to a bifurcation in the law of motion of the countries' growth rates but it assigns the threshold effects to the technological realm, i.e. the innovative and the absorptive capacity of countries.

Empirically the notion of convergence clubs received support from findings on the existence of multiple growth regimes (Durlauf and Johnson, 1995) and research on the world income distribution which in the modern era saw the emergence of "twin peaks" (e.g. Quah, 1997). The existence of a bimodal distribution of per-capita income across countries implies an accumulation of countries at very different levels of income. Convergence of countries to different per capita incomes is clearly incompatible with a general growth convergence among all countries but perfectly in line with convergence within clubs.

Closely related to our work are the contributions by Castellacci (2008; 2010) and Castellacci and Archibugi (2008) who take up the issue of technology clubs empirically and use cluster techniques in order to sort countries into three technology clubs. Castellacci (2008) uses the number of journal articles as proxy for the innovative capacity and the literacy rate of the human capital variable representing the absorptive capacity. We undertake a similar exercise, though our variables for the cluster analysis are different since we use the gross expenditure on R&D in percent of GDP as technology variable and the literacy rate and the average years of schooling as proxy for the absorptive capacity. Moreover, our cluster analysis is different from Castellaci (2008) who employs a classification and regression tree (CART) analysis on top of a hierarchical cluster analysis. The CART analysis subsequently determines the thresholds to distinguish clearly between the innovative, the imitation and the stagnation club, starting with the split between the stagnation and the imitation group.

Our approach simply combines a hierarchical cluster analysis with a non-hierarchical cluster approach. The advantage of our approach, however, is that the number of clusters is not predetermined but is based on a decision rule. Nevertheless we also end up with a tripartite cluster solution.

For our growth regressions we draw heavily on Benhabib and Spiegel (1994) and Crespo, Martín and Velázques (2004) as the growth equation we estimate is similar to their specifications. Starting from a Cobb-Douglas production function Benhabib and Spiegel (1994) endogenise the productivity term by introducing a law of motion for productivity. According to this law of motion for productivity, the change in productivity is a function of human capital and the country's distance to the technological frontier, i.e. the technology gap. Econometrically, the Benhabib-Spiegel approach leads to the substitution of the growth rate of human capital with the *level* of human capital. Benhabib and Spiegel also introduce a catch-up term which is created by interacting human capital with the technology gap. We will employ this catch-up term for measuring the growth effects from spillovers. In addition we will estimate our growth regression with the simply technology gap variable. The growth regression we estimate resembles that of Crespo, Martín and Velázques (2004) who estimate the growth effects of spillovers for a sample of OECD countries using the interaction between human capital and the technology gap as the catch-up variable.

We add to the existing literature on spillovers and absorptive capacity by searching for non-linearities in the catch-up effects (in addition to those introduced by the fact that the catch-up variable is an interaction term). To this end we employ the threshold estimation technique developed by Hansen (2000). The main advantage of the threshold estimation procedure is that the threshold that splits the sample is not determined a priori but is determined by the data during the estimation process.

We detect thresholds in the human capital variable and relate them to the technology club literature. Given this theoretical framework we expect to find (at least) three different regimes with respect to the catch-up effect which we associate with the innovation, the imitation and the stagnation club. Moreover, we expect that the medium regime resulting from the threshold regressions – which we associated with the imitation club – to benefit most strongly form spillovers and that they therefore have the largest growth effects from the catch-up variable. In contrast, no or only very small growth effect from spillovers are expected for the low regime, i.e. the country group with the lowest level of human capital which we associate with the stagnation club.

3 Data

Our primary source of data is the World Bank's World Development Indicators (WDI) database. From the WDI we take GDP per capita, gross fixed capital formation, labour force and population data as well as the literacy rate of the population aged 15 or over. We collect these variables for the period 1980-2009. We complement the human capital variables with data from the Barro-Lee database from which we use the average years of schooling. Our main innovation variable is gross expenditure on R&D (GERD) in percentage of GDP for which – due to our global coverage of countries – we turn to the UNESCO Beyond 2020 data base. The principal time coverage of the UNESCO data base is from 1996 to 2007.

For the cluster analysis we have to impute some of the data in order to end up with a satisfactorily large dataset. In particular we lack data on the literacy rate for most developed countries as this type of data is typically not collected anymore. Hence, we follow the approach of UNEP in their calculation of the Human Development Index (HDI) and assume a literacy rate of 99% for these countries. Moreover, UNEP provides literacy rate data for some countries where the WDI databank does not, so we complement the WDI data with UNEP data in these instances. Unfortunately, we also lack data on the R&D expenditure for a rather large number of countries, and in particular for African countries. In order not to lose too many observations we rely on regional averages provided by UNESCO (2010), except for the LDC countries where we apply the LDC's average rate. While this may be seen as a shortcoming of our approach for the clustering analysis we believe that the regional approximations are a permissible imputation method as we do not expect any serious outliers in the group of missing countries. In some instances, where we feel uneasy about using the region's average we either use the value of a neighbouring country or drop the country from the sample.

The capital stocks needed for the growth regressions are calculated with the perpetual inventory method with 1980 as the base year. We assume a depreciation rate of 6% (as Hall, 1999) and use the 1980-2005 annual growth rate to arrive at the capital stock in 1980.

4 Identifying technology clubs

Given our hypothesis of distinct convergence clubs based on innovative and absorptive capacities, we first try to identify such convergence clubs and its members by way of cluster analysis. There exists a wide range of potential variables that may reflect the technological capacity and absorptive capacity of countries. As in Castellacci (2008) we adapt a parsimonious approach with respect to the number of variables we use for the cluster analysis. We rely on the gross expenditure on R&D as a share of GDP to proxy for the innovative capability of countries. With respect to the absorptive capacity we take the Nelson and Phelps (1966) view that the level of human capital is the main determinant of absorptive capacity. We use two human capital indicators, namely the literacy rate and the average years of schooling. The choice of these variables is to a large extent also determined by the availability of data. We base the analysis on the data for the average of the years 2005-2009.

The cluster analysis is performed in two steps. We start out with a hierarchical cluster analysis using the average linkage method. This delivers a first clustering result for a total of 142 countries with the number of groups (or clubs) not being pre-determined. We use the Calinski-Harabasz method as stopping rule for determining the number of clubs. In a second step we use a non-hierarchical cluster analyses that starts out with a given number of clubs which we obtained from the hierarchical cluster analysis. The advantage of the non-hierarchical cluster process is that it allows repeated resorting of countries into different clusters during the course of the clustering process which is not the case in a hierarchical cluster process. The possibility of resorting countries tends to lead to more distinct clusters each with more similar elements. However, in the non-hierarchical cluster procedure the number of clusters is determined ex-ante.

The hierarchical clustering procedure delivers a first cluster result with the stopping rule and the cluster tree suggesting either a clustering into 3 or 6 distinct country groups[12]. As a next step we perform a non-hierarchical cluster analysis imposing alternatively 3, 4, 5 or 6 clusters. In our case the results from both methods are rather similar with only a slight reordering of countries. Comparing the values of Calinski-Harabasz stopping rule for the non-hierarchical cluster solutions with alternative numbers of pre-defined clusters confirms the preferred number of clubs being three. The result from our cluster analysis is presented in Tables 1a and 1b.

The first cluster consists of 38 countries with low values of both the innovation and the human capital variables. The group average for the R&D expenditure in percentage of GDP (R&D/GDP) is only 0.26%. The average literacy rate is just above 60% with the average person having about 4.3 years of schooling. Given our theoretical model we label this cluster the stagnation club (or marginalised group). Note also that this club comprises about a third of the total population of all the countries in the sample. The second cluster, which is the largest comprising 80 members, also scores low on the R&D dimension with a R&D/GDP ratio of about 0.5%. However, the human capital levels are rather high with a literacy rate of about 93% and on average almost 8.5 years of schooling. The characteristics of this cluster fits well with the notion of the imitation club whose members do not perform a lot of their own R&D but are quite capable of adopting foreign technologies. Finally, the third cluster includes 24 countries with a high R&D/GDP ratio amounting to 2.2%, close to complete literacy among the population and on average 10.7 years of schooling. These characteristics we associate with the innovation club consisting of the technology leaders.[3]

[1] We exclude Israel from the analysis as it represents an outlier due to its very high R&D expenditures.
[2] In Calinski-Harabasz method large values for the Pseudo-F value suggest more distinct clusters. For the cluster dendrogram and the results for the different cluster solution see Appendix A4.
[3] The result from the cluster analysis remains qualitatively the same if we perform the cluster analysis with a reduced country sample for which R&D data is available with hardly any differences in the club membership of the countries in the two methods. The major difference is that the number of the members in the stagnation club is largely reduced because of the many missing African countries.

Table 1a: Characteristics of the technology Clubs resulting from the cluster analyses, 2005-2009

cluster #		**R&D expendi-ture (% of GDP)**	**literacy rate (in %)**	**average years of schooling**	**number of coun-tries**	**assigned name of club**	**share of total population**
1	cluster mean	0.26	60.02	4.27	38	stagnation	34.26
	std. dev.	0.16	14.14	1.37		(marginalized)	
	min	*0.03 (Sambia)*	*26.2 (Mali)*	*1.24 (Mozambique)*			
	max	*0.80 (India)*	*84.2 (Syria)*	*7.50 (Ghana)*			
2	cluster mean	0.47	92.94	8.41	80	imitation	52.24
	std. dev.	0.31	6.23	1.52		(follower)	
	min	*0.04 (Saudi Arabia)*	*72.6 (Algeria)*	*4.15 (Myanmar)*			
	max	*1.40 (China)*	*99.8 (Latvia, Cuba)*	*11.49 (Hungary)*			
3	cluster mean	2.22	98.88	10.74	24	innovation	13.50
	std. dev.	0.74	0.92	1.23		(leader)	
	min	*1.12 (Estonia)*	*94.7 (Singapore)*	*8.47 (Singapore)*			
	max	*3.68 (Sweden)*	*99.8 (Estonia)*	*12.75 (Czech Republic)*			

Note: Club averages are unweighted averages based on country values. Countries do not exactly coincide with Augur reporters (e.g. China and Macao are two distinct reporters here). Literacy rate of population aged 15+. The three technology clubs include the following countries:
Stagnation club: Cote d'Ivoire, Papua New Guinea, Haiti, Central African Republic, Congo, Dem. Rep., Mozambique, Burundi, Gambia, Senegal, Mal, Benin, Mauritania, Nepal, Bangladesh, Togo, Liberia, Pakistan, Morocco, Niger, India, Afghanistan, Rwanda, Sudan, Sierra Leone, Yemen, Rep., Guatemala, Malawi, Iraq, Syrian Arab Republic, Lao PDR, Ghana, Congo, Rep., Tanzania, Uganda, Zambia, Cameroon, Egypt, Arab Rep., Cambodia.
Imitation club: Ecuador, Latvia, Tunisia, Tonga, Maldives, Algeria, Mauritius, Belize, Romania, Cuba, Panama, Mexico, Tajikistan, Malaysia, Nicaragua, Iran, Islamic Rep., Trinidad and Tobago, El Salvador, Macao SAR, China, Jordan, Qatar, Italy, Costa Rica, Lesotho, Bolivia, Jamaica, Poland, Serbia, Bahrain, Slovak Republic, Portugal, Gabon, South Africa, Zimbabwe, United Arab Emirates, Libya, Croatia, Paraguay, Bulgaria, Venezuela, RB, Indonesia, Botswana, Kuwait, Vietnam, Namibia, Malta, Saudi Arabia, Mongolia, Swaziland, Turkey, Kazakhstan, Cyprus, Moldova, Russian Federation, China, Dominican Republic, Greece, Myanmar, Chile, Thailand, Sri Lanka, Colombia, Albania, Honduras, Argentina, Kenya, Barbados, Armenia, Brazil, Kyrgyz Republic, Philippines, Fiji, Spain, Peru, Hong Kong SAR, China, Uruguay, Guyana, Hungary, Lithuania, Ukraine.
Innovation club: Austria, Estonia, France, Canada, Singapore, Iceland, Germany, Finland, United Kingdom, United States, Australia, Korea, Rep., Czech Republic, Netherlands, Japan, Sweden, Ireland, Belgium, New Zealand, Denmark, Switzerland, Slovenia, Luxembourg, Norway.

Table 1b shows the differences in the clubs means across the three variables. As can easily be seen, there is a huge difference between the innovation group (cluster 3) and the imitation group (cluster 2) in terms of R&D/GDP amounting to 1.75 percentage points which is more than three times the current value of the imitation group. In contrast, the differences between these two groups in the literacy rate and average years of schooling are less dramatic as the imitation group also scores high on these dimensions. The opposite situation can be observed when comparing the imitation club with the stagnation club as the difference on the R&D/GDP-ratio is small relative to the differences in the human capital variables. Therefore it seems that the distinctive feature separating the innovation club from the imitation club is indeed primarily the R&D/GDP

ratio while the imitation club and the stagnation club mainly differ in terms of human capital which we claim is relevant for a country's absorptive capacity.

Table 1b: Differences between the Technology Clubs (cluster means), 2005-2009

cluster #	R&D expendi-ture (% of GDP)	literacy rate (in %)	average years of schooling
3-2	1.75	5.95	2.33
3-1	1.96	38.86	6.47
2-1	0.20	32.92	4.14

Note: Differences in R&D expenditures and literacy rates in percentage points; differences in average years of schooling in years.

In Table 2 we relate the result from the cluster analysis to the world regions. The club membership across the regions unveils only few surprises. We find the members of the innovation club mainly in Europe (above all North Europe and Central Europe) and in the Americas and European Offsprings (above all the US but also the whole of the Other Developed region). There are also several technology leaders in South East and East Asia, namely Japan, Singapore and South Korea (the latter two belonging to the East Asia High Income region).

This leaves the whole of Africa and West Asia without any technology leader. The same is true for India and Other South Asia. The Former Soviet Union (Commonwealth of Independent States) shows one technology leader which is – a bit surprising – Estonia. Estonia as well as the Baltic countries, however, are EU member and in the meantime economically and politically more orientated towards Europe than the CIS region.

Next to the clustering of Estonia as an innovating country, the second surprise in our clustering result is the fact that India is sorted into the stagnation club, despite a rather high R&D/GDP ratio. For example, India's R&D/GDP ratio is higher than that of China. The reason why in our analysis India ends up in the stagnation club is its still very low literacy rate.[4]

In absolute terms, the great majority of members belonging to the stagnation club are found in the South Africa region, 22 out of the total of 38 countries. But also two thirds of the countries in Other South Asia, half of North Africa and still a quarter of Other East Asia (Laos, Cambodia, Papa New Guinea) are members of the stagnation club. Other South Asia also has the lowest average R&D/GDP ratio and together with India the lowest literacy rate.

[4] According the UNDP's Human development index India's literacy rate would be somewhat higher, around 66% for the period 1999-2007. In order to be in line with the majority of the other countries we stick to the World Bank data (WDI) for the Indian literacy rate. Moreover, there are vast difference in the literacy rates within India. According to Indian census figures from 2001, literacy rates in India range from only 47% in Bihar to more than 90% in Kerala. See http://india.gov.in/knowindia/literacy.php.

Table 2: Club membership across world regions

augur region	number of countries	stagnation club	imitation club	innovation club	R&D expenditure (% of GDP)	literacy rate (in %)	average years of schooling
South East and East Asia							
JA	1			1	3.39	99.00	11.26
CN	2		2		0.76	93.75	7.56
EAH	3		1	2	2.05	96.10	9.93
EAO	12	3	9		0.26	88.30	7.10
Europe							
EUC	7			7	2.19	99.00	10.26
EUE	10		8	2	0.77	98.37	10.15
EUN	4			4	2.82	99.00	10.87
EUS	8		6	2	1.15	97.13	9.62
EUW	1			1	1.80	99.00	9.21
Americas & European Offsprings							
US	1			1	2.70	99.00	12.09
AM	10		10		0.48	93.05	8.07
ACX	15	2	13		0.40	86.49	7.85
OD	3			3	1.73	99.00	11.85
Africa & West Asia							
AFN	6	3	3		0.43	72.30	5.84
AFS	31	22	9		0.29	66.49	5.07
WA	11	3	8		0.25	85.79	6.78
South Asia & CIS							
IN	1	1			0.80	62.80	4.68
ASO	6	4	2		0.24	64.22	5.08
CI	10		9	1	0.58	99.52	10.04
WORLD	142	38	80	24	0.71	85.13	7.70

Note: Region and world averages are unweighted averages based on country values. Countries do not exactly coincide with Augur reporters (e.g. China and Macao are two distinct reporters here)

5 Estimating Growth Effects of Technology Spillovers

The tripartite technology cluster solution presented in the previous section is based on the assumption that countries with different characteristics benefit to varying degrees from foreign technology spillovers. In this section we investigate whether we can detect such spillovers in a growth regression framework. We associate these spillovers with the effect of a catch-up term on economic growth where this catch-up term is an interaction of the technology gap and human capital. In particular we are interested whether the strength of such growth effects from the catch-up term vary with the level of human capital.

Starting point is the traditional (Cobb-Douglas) production function. By taking logs and first differences we get:

$$(1) \qquad \Delta ln\, Y_{it} = \alpha \cdot \Delta ln\, K_{it} + \beta \cdot \Delta ln\, L_{it} + \Delta ln A_{it} + \varepsilon_{it}$$

where ΔlnY_{it} is the growth rate of GDP of country *i* in period *t*, ΔlnK_{it} is the growth rate of the physical capital stock, ΔlnL_{it} is the growth rate of labour and ΔlnA_{it} is total productivity productivity growth. ε_{it} denotes the error term.

In line with the endogenous growth literature we assume a law of motion for productivity which takes the form

$$(2) \qquad \Delta \ln A_{it} = \gamma + \delta \cdot \Delta ln\, H_{it} + \phi \cdot \left(\frac{Y^{max} - Y_{it}}{Y^{max}} \cdot \mathrm{H}_{it} \right)$$

Equation (2) assumes that the change in productivity depends on the *stock* of human capital, H_{it} which we proxy by the average years of schooling and the technology gap. While there are alternative definitions of the technology gap in the literature, we opt for calculating country *i*'s technology gap as the difference between the technologically leading country's productivity and the productivity of country *i*, divided by the leader's productivity. In our sample the United States are the technology leader throughout the periods. The productivity of country *i* is derived from the Cobb-Douglas production function following Hall and Jones (1999) yielding $\mathrm{A}_i = \frac{\frac{Y_i}{L_i}}{\left(\frac{K_i}{Y_i}\right)^{\frac{\alpha}{1-\alpha}}}$.

Based on the calculated productivities we derive the productivity gap by taking the logarithm and normalising the logged productivity gaps so that they lie within the range from 0 (leader) to 1.

Equation (2) is basically the Benhabib and Spiegel (1994) framework which stresses the (mainly indirect) role of human capital for the growth process through the impact on productivity growth.

Note that in equation (2) the coefficient of the technology gap, ϕ, is a function of human capital, H_{it}. This is because the potential for catching up of countries with a technology gap is expected to depend on the country's absorptive capacity which we proxy by human capital. A country's absorptive capacity, according to Cohen and Levinthal (1989), is "the ability to identify, assimilate, and exploit knowledge from the environment" – in our case from other countries. Many other variables may matter for absorptive capacity but here we want to focus on human capital as enabling factor for technology spillovers.

Using human capital as proxy for a country's absorptive capacity implies that human capital has a double role: it feeds directly into productivity growth but it is also relevant for the potential spillovers that arise from the technology gap.

As mentioned earlier, more closely related to the absorption of spillovers than the technology gap is the catch-up term used by Benhabih and Spiegel (2005) and Crespo, Martín and Velázques (2004) which is built by interacting human capital with the technology gap, $H_{it} \cdot \frac{A_t^{max} - A_{it}}{A_t^{max}}$. In this case the law of motion for productivity becomes:

(2')
$$\Delta \ln A_{it} = \gamma + \delta \cdot \mathrm{H}_{it} + \phi(H_{it}) \cdot \left(H_{it} \cdot \frac{A_t^{max} - A_{it}}{A_t^{max}} \right)$$

Combining equation (2') with equation (1) yields the following growth regression:

(3)
$$\Delta \ln Y_{it} = \gamma + \alpha \cdot \Delta \ln K_{i,t} + \beta \cdot \Delta \ln L_{i,t} + \delta \cdot \mathrm{H}_{i,t-1} + \phi\left(H_{i,t-1}\right) \cdot \left(H_{i,t-1} \cdot GAP_{i,t-1}\right) + \eta_t + \mu_i + \varepsilon_{i,t}$$

where $GAP_{i,t-1}$ is defined as $\left(\frac{A_{t-1}^{max} - A_{i,t-1}}{A_{t-1}^{max}}\right)$ and $\left(H_{i,t-1} \cdot GAP_{i,t-1}\right)$ is the catch-up term. In our empirical application we use lagged values of the human capital stock as well as the technology gap and we include time dummies (η_{it}) as well as country dummies (μ_{it}).

The main variable of interest is the catch-up term. The coefficient of the catch-up term is intended to capture the growth effect induced by international technology spillovers. Obviously, we expect a larger growth effect for countries with large technology gap (as they have the highest potential for international technology spillovers) and larger human capital stocks (as they have higher absorptive capacity). In other words we expect a positive sign for the cient $\phi(H_{i,t-1})$.

However, as pointed out above we allow the strength of this growth effect to depend on the level of human capital. To capture this we apply threshold regression techniques. In the threshold regression framework human capital is used as the threshold variable and we allow for different coefficients of the technology gap for the two sub-samples which result from the sample-split.

This threshold regression model takes the form:

(4) $$\Delta ln\, Y_{it} = \gamma + \alpha \cdot \Delta ln\, K_{it} + \beta \cdot \Delta ln\, L_{it} + \delta \cdot H_{i,t-1} + \theta_1 \cdot \left(H_{i,t-1} \cdot GAP_{i,t-1}\right)(if\ H_{i,t-1} \leq \lambda) + \\ +\theta_2 \cdot \left(H_{i,t-1} \cdot GAP_{i,t-1}\right)(if\ H_{i,t-1} > \lambda) + \eta_t + \mu_i + \varepsilon_{it}$$

Where λ denotes the threshold in the human capital variable.

We will also estimate a variant of this model where we replace the catch-up term, $\left(H_{i,t-1} \cdot GAP_{i,t-1}\right)$, with the technology gap, $GAP_{i,t-1}$.

Before we implement this threshold regression we first test whether we can detect growth effect from the catch-up term and the technology gap respectively by ordinary least square (OLS) regressions. So we assume for the moment $\phi\left(H_{i,t-1}\right) = \phi$ and run pooled panel and fixed effects estimation of equation (3).

Our sample is an (almost) balanced panel of 76 countries for the time span 1980-2009 where we divide this time span into six 5-year periods. Since we estimate (log) differences we end up with a panel of dimensions *i=76* and *t=5*.

The results from the OLS panel regression are presented in Table 3.

Table 3: OLS estimation of growth effects from spillovers

Dependent variable: Δ log GDP per capita *(Δ ln Y_{it})*

	pooled model		fixed effects		
	base	broad	base	broad	full
	(1)	(2)	(3)	(4)	(5)
Δ ln $K_{i,t}$	0.48441 ***	0.48192 ***	0.41222 ***	0.41752 ***	0.41675 ***
	0.035	0.035	0.066	0.066	0.066
Δ ln $L_{i,t}$	0.26048 ***	0.23888 **	0.24886	0.24349	0.24541
	0.091	0.095	0.170	0.169	0.171
$H_{i,t-1}$	-0.00541 **	0.00306	-0.04086 ***	-0.01184	-0.01717
	0.002	0.002	0.014	0.012	0.027
$(HxGAP)_{i,t-1}$	0.00827 ***		0.03149 ***		0.0058
	0.002		0.008		0.031
$(GAP)_{i,t-1}$		0.09789 ***		0.37196 ***	0.30653
		0.027		0.089	0.352
constant	0.06507 ***	-0.02857	0.22601 **	-0.11915	-0.05851
	0.021	0.034	0.095	0.122	0.308
time dummies	no	no	yes	yes	yes
country dummies	no	no	yes	yes	yes
F-test	63.837	68.212	9.556	9.753	8.667
R^2	0.414	0.417	0.571	0.572	0.572
R^2-adj.	0.407	0.410	0.451	0.452	0.450
Obs.	380	380	380	380	380

Note: Estimated with STATA 11. Robust standard errors are shown below the coefficients. ***, **, * indicate statistical significance at the 1%, 5% and 10% level respectively.

In columns (1) and (2) we estimate a pooled version of equation (3) with $\phi(H_{i,t-1}) = \phi$. In the base specification, specification (1), we include the (lagged) catch-up term, while in the specification (2) the (lagged) technology gap is included. The results are largely as expected: we find a positive and statistically highly significant effect for the growth rate of the capital stock. Specification 1 suggests that a 1 percentage point increase in the growth of the capital stock increases the GDP growth by 0.48 percentage points.[5] We also find a positive and statistically significant impact of the growth rate of the labour force, about half as large as that of the capital stock. [6] Specification (1) also suggests a small but statistically significant and positive effect of human capital while in specification (2) the significance of the coefficient of human capital is lost. Most importantly for our purposes, both specifications yield a positive effect for the catch-up term and the productivity gap term respectively. This indicates that

[5] This growth effect appears to be large but remember that we use 5-year periods.

[6] In the growth literature population or labour force typically does not have strong growth effects. This may have to do with the fact that much of the literature uses GDP per capita as dependent variable while our dependent variable is GDP.

countries which are further away from the technological frontier tend to grow faster.

Note that the technology gap in specification (2) is in a way the counterpart of the initial income term in neo-classical growth regressions as these two variables are highly correlated. Neo-classical growth regressions à la Mankiw, Romer and Weil (1992) interpret the coefficient of the income variable as indicating out-of-steady-state-convergence of countries with the same technology. In contrast, in the endogeneous growth framework, the process of convergence is triggered by a catch-up in the productivity level of technologically backward countries. This is why we associate the coefficient of the technology gap in the econometric model with technological catching-up induced by international spillovers.[7]

Specifications (3) to (5) report the results for the fixed effects estimations. The coefficient of capital growth does not change much but the growth of the labour force loses its statistical significance. Most importantly, however, the fixed effects model also yields a positive and statistically highly significant coefficient for the catch-up variable and the technology gap variable respectively. Starting with specification (4), the size of the coefficient of the technology gap suggests that a 0.1 unit increase in the technology gap (e.g. an increase from 0.7 to 0.8) is associated with 3 percentage points (0.1 x 0.309) higher GDP growth. Again, it should be noted that this large effect applies to 5-year growth rates.

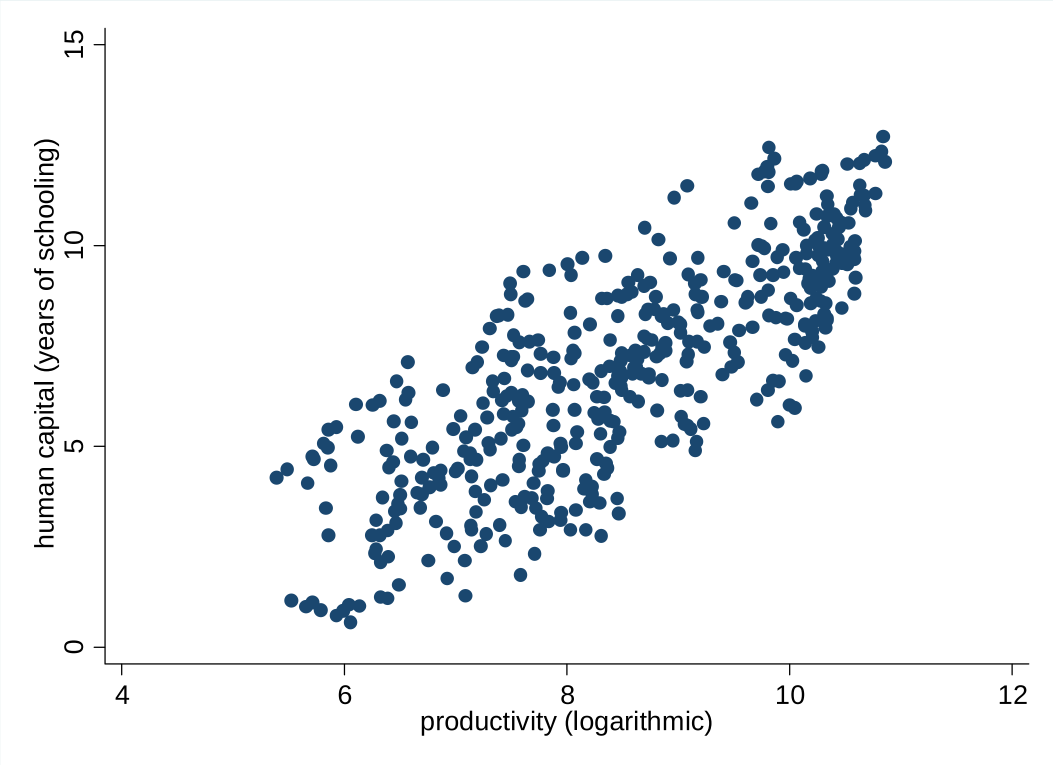
In specification (3) the growth effects of the spillovers are proxied by the human capital-technology gap interaction, $(H_{i,t-1} \cdot GAP_{i,t-1})$. The positive sign of the catch-up term's coefficient suggests that the growth effect from the technology gap is the greater the higher is the country's level of human capital.

The positive correlation between productivity and stocks of human capital, depicted in Figure 1, means that there is on the one hand a great potential for catching-up of countries with low productivity (high technology gap) as shown in specification (4). On the other, the lack of human capital (absorptive capacity) may significantly reduce the strength of such a catch-up process or even prevent it.

Since the catch-up variable in specification (3) is an interaction term, the effect of the technology gap on GDP growth is non-linear and cannot be read off directly from the coefficient which is estimated to be 0.031 (save for a country with zero human capital). The coefficient of the catch-up term implies that at the average level of human capital in the sample (5.4 years of schooling), the growth effect of a 0.1 unit change in the technology gap is about 1.7 percentage points (0.03(coefficient) x 5.4(average value of human capital-technology gap)x0.1).

[7] For a discussion of different interpretation of growth regressions in the neo-classical growth framework and the endogenous growth framework see Klenow and Rodriguez-Clare (1997).

Figure 1 Scatter between human capital and productivity across country sample (1980-2009)



As mentioned before we prefer the specification with the human capital-technology gap interaction term (the catch-up term) because it better fits the idea that a higher level of human capital facilitates catching-up. However, from an econometric point of view specification (3) may be considered problematic. Since it includes an interaction term, it should also include both elements of the interaction term separately (see e.g. Jaccard and Turrisi, 2003). Otherwise, the scaling of variables may have a large effect on the interaction term. We show this in specification (5) which is the same as (3) only that it includes both the technology gap and the capital-technology gap interaction term. In this specification both the productivity gap and the interaction term are still positive but smaller in size and above all, not statistically significant anymore. We think that this may be due to the fact that this specification contains two conceptually similar variables in the sense that both the technology gap variable and the human capital-technology gap interaction are intended to capture the growth effects from international spillovers.

In line with the literature (e.g. Benhabib and Spiegel, 2005; Crespo, Martín and Velázques, 2004) we consider the catch-up term to be an economically meaningful variable on its own and we maintain specification (3) as well as (4) for the threshold regressions.

We now turn to the estimation of catch-up effects with threshold regression model presented in equation (4). As pointed out above the threshold model allows for non-linearities in the growth effects stemming from the catch-up term. Relating this to the theory of technology clubs we would expect such threshold somewhere at the lower range of the distribution of human capital stocks. Such a threshold separates the sample into a low regime and a high regime where we associate the low regime with the stagnation club.

Potentially we may also find further thresholds. In particular we may find a threshold which can be related to the separation of the imitation and the innovation club. Such a model with two thresholds, (λ_1) and (λ_2) corresponds to three distinct regimes with respect to the growth effect of the catch-up term (θ_1, θ_2 and θ_3). Associating the low, the medium and the high regimes with the stagnation club, the imitation club and the innovation club we expect the highest catch-up effects from the group of the imitation group, i.e. the medium regime.

Note that the threshold (or thresholds) are not pre-determined but is (are) selected in the course of the estimation process by repeatedly estimating the model each time with an alternative threshold. In our case we estimate the model with thresholds at each percentile of the data. The final threshold is found by comparing the explanatory power of the models and selecting the model with the lowest sum of squared errors[8].

The results from the threshold regression allowing for non-linearities in the catch up variable (variant I) and the technology gap variable (variant II) are shown in Table 4.

[8] Once a threshold has been found its statistical significance can be tested this test implies testing the null hypothesis that the two coefficients are the same.
Under this null hypothesis the threshold λ is not defined so that bootstrapping methods are recommended for obtaining p values for the likelihood ratio test.

Table 4: Threshold regression testing non-linearities in the catch-up effects

Dependent variable: Δ log GDP per capita *(Δ ln $Y_{i,t}$)*

Threshold variable: one period lagged human capital (*$H_{i,t-1}$*)

Variables	Threshold 1 (I.1)	Threshold 2 (I.2)
Δ ln $K_{i,t}$	0.425***	0.397***
	0.0653	0.0665
Δ ln $L_{i,t}$	0.211	0.294*
	0.172	0.174
$H_{i,t-1}$	-0.0452***	-0.0435***
	0.0136	0.0135
(H x GAP)$_{i,t-1}$ low regime	0.00962	0.0206*
	0.0114	0.0116
(H x GAP)$_{i,t-1}$ medium regime		0.0338***
		0.00795
(Hx GAP)$_{i,t-1}$ high regime	0.0284***	0.0271***
	0.00807	0.00775
constant	0.282***	0.252**
	0.0968	0.099
F-stat	9.300	9.308
R^2	0.583	0.588
Threshold	3.743	8.401
Percentile	17	70
P-value	0.006	0.001
Obs.	380	380

Variables	Threshold 1 (II.1)	Threshold 2 (II.2)
Δ ln $K_{i,t}$	0.386***	0.412***
	0.0667	0.0627
Δ ln $L_{i,t}$	0.289*	0.247
	0.169	0.173
$H_{i,t-1}$	-0.00716	-0.0189
	0.0116	0.0123
GAP$_{i,t-1}$ low regime	0.429***	0.309***
	0.0837	0.0968
GAP$_{i,t-1}$ medium regime		0.373***
		0.0904
GAP$_{i,t-1}$ high regime	0.349***	0.343***
	0.083	0.088
constant	-0.183	-0.0522
	0.119	0.129
F-stat	9.811	8.746
R^2	0.585	0.587
Threshold	8.762	3.933
Percentile	75	19
P-value	0.005	0.013
Obs.	380	380

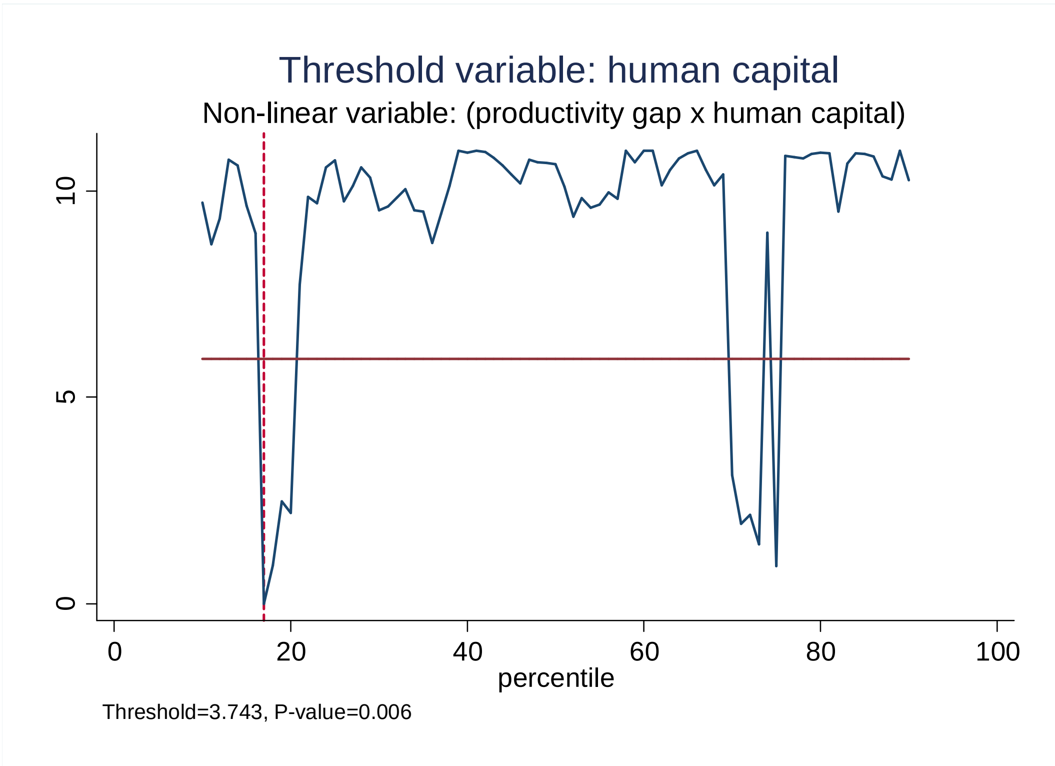
Note: Estimated with STATA 11. All estimations include country fixed and time fixed effects. Robust standard errors are shown below the coefficients. ***, **, * indicate statistical significance at the 1%, 5% and 10% level respectively.

For the discussion of the results we concentrate on the variables related to international spillovers, i.e. the catch-up variable $(H_{i,t-1} \cdot GAP_{i,t-1})$, and the technology gap, $GAP_{i,t-1}$.

We start with the results using the catch-up term. Column (I.1) shows that the data suggests a first threshold at the 17th percentile of the human capital values which corresponds to approximately 3.7 years of schooling. The coefficients of the catch-up term are positive for both the low and the high regime. However, the coefficient of the low regime is much smaller and statistically not significant. In contrast, the coefficient for the high regime, i.e. for countries with more than 3.7 years of schooling, is estimated to be 0.028 and is statistically significant at the 1% level. This corresponds to the pattern we expected: high growth effects from spillovers for country with sufficient human capital (absorptive capacity) but little or no such growth effects for the countries of the low regime which are below the human capital threshold (stagnation club).

The graph in Figure 2 shows likelihood ratios for models with alternative thresholds and the confidence intervals of the estimated threshold. The graph is obtained by performing a likelihood ratio test. This test consists of estimating equation (4) with the threshold imposed alternatively at each of the percentiles in the range of the 10th to the 90th percentile. In the actual likelihood test the residual sum of squares of the models with the alternative thresholds are compared with that of the threshold found in the estimation process. The horizontal line at the value of 5.94 is the critical value for the likelihood ratio at the 10% level of significance. The graph in Figure 2 represents the likelihood ratio that results from the likelihood ratio test that compares the selected model with the model setting the threshold at the respective percentile. For all alternative models with likelihood values above this critical value of 5.94 we have a 90% probability that the fit of the selected model is significantly better, i.e. the alternative models have significantly larger residual sums of squares than the selected model.

Figure 2 Likelihood ratio of the threshold



In our case the threshold at the 17th percentile is estimated rather precisely because both to the left and to the right of the 17th percentile the likelihood ratios of alternative models (i.e. models with the threshold at neighbouring percentiles) increase quickly and surpass the critical value in close vicinity of the

17th percentile. However, the confidence interval is very broad, reaching from shortly below the 20th percentile (where the graph and the line intersect the first time) to about the 75th percentile of the data. The reason for this very broad confidence interval is a drop in the likelihood ratio between the 70th and 80th percentile. This indicates that it is worth searching for an additional threshold.

The results from the threshold regression that allows for an additional threshold are reported in column (I.2) in Table 4.

The second threshold splits the sample of countries above 3.7 years of schooling into two further regimes (medium and high). The threshold is suggested to be at the 70th percentile corresponding to approximately 8.4 years of schooling. This results into a splitting of the sample into three distinct regimes. As can be seen the model finds the largest coefficient of the $(H_{i,t-1} \cdot GAP_{i,t-1})$ variable for the medium regime, amounting to 0.034. For the high regime, i.e. the countries with the highest level of human capital the coefficient is found to be considerably lower (0.027). Yet, even lower is the coefficient for low regime (stagnation club) though it is much larger in the two-threshold model compared to the one-threshold model. Moreover, it is statistically significant at least at the 10 percent level.

In columns (II.1) and (II.2) of Table 4 we repeat the threshold estimation, this time including the technology gap variable. The pattern of the coefficients for the three regimes is as before with the countries belonging to the medium regime being able to reap the largest growth effects from their technology gap (coefficient: 0.373). Moreover, the thresholds are suggested to lie at similar values of human capital: the lower threshold at the 19th percentile which corresponds to 3.9 years of schooling and the upper threshold at the 75th percentile which corresponds to 8.8 years of schooling. Note that is this specification, the first threshold detected by the data is the higher threshold.

From the results of the threshold regressions we can conclude that countries with lower productivity tend to grow faster but that the extent to which countries can capitalise their "advantage from backwardness" depends on their level of human capital. Below a certain threshold, countries can reap only rather low growth effects from their productivity gap while these effects are largest for the medium regime. Hence, by and large the results from the threshold regression are in line with the idea of technology clubs where a group of countries – the stagnation club – finds it hard to exploit the potential for higher growth arising from the technology gaps due to lack of absorptive capacity. In contrast, a second group of countries – the imitation club – benefits to a much larger degree from their technology gap. Finally, the member of the innovation club – according to our estimates – also benefit from technology spillovers though to a lesser extent than the imitation group.

6 Implications of the results for the Augur scenarios

One dimension in the AUGUR scenarios – reduced government (consolidation), bipolar world, multipolar world and regionalisation – is the promotion of convergence. Obviously, the scenarios differ with respect to the efforts made to integrate previously marginalised countries in the world economy and initiate or strengthen catching-up processes.

This paper was intended to highlight the huge differences in the innovative and absorptive capacity of countries which we associated with R&D and human capital. Our cluster analysis showed these differences by forming three groups of countries or clubs. In the regression analyses, we concentrated more on the role of absorptive capacities and our results suggest that countries had had a rather differentiated experience with regards to technological catching-up over the past 30 years. According to our results countries with at least intermediate levels of human capital experienced strong growth effects from international spillovers (due to their technology gaps). In contrast, countries with very low absorptive capacity these growth effects from technological catch-up is much more modest, despite the fact that these countries tend to have large technology gaps which potentially give rise to strong spillover effects. The results for the growth effects for model countries with club average values of human capital and the productivity gap are summarised in Table 4 for each of the three clubs.

Table 4: Growth effects from technological catch-up by technology club

	human capital	productivity gap (club average)	catch-up term	estimated coefficient of catch-up term	predicted growth effect from catch-up	actual average growth (1980-2009)
low regime	2.62	0.97	2.54	0.0206	0.052	0.163
medium regime	6.15	0.83	5.10	0.0338	0.173	0.180
high regime	9.86	0.45	4.43	0.0271	0.120	0.144

We believe that our results are helpful for shaping the scenarios for at least two reasons. Firstly, we believe that the scenarios should reflect that strengthening the catching-up process of middle income regions such as South America or Other South East Asia should be much easier to achieve than initiating a convergence process in countries that so far were technologically left behind. This element seems to be absent in the scenarios. Secondly, our results suggest that next to physical capital, the development of human capital – indirectly through the catch-up mechanism – also plays a crucial role for the growth process. The role of the skill structure of the labour force and more generally the educational level is one of the topics debated in recent work on the possible transition of the Middle Eastern and North African (MENA) countries. Havlik and Richter (2011) for example point out the very different initial situation of the MENA region in this respect in their comparison of the transition phase of the

Central, East and South East European countries with that of the potential transition of the MENA countries.

Common to all scenarios is that the *international* channels through which *income* convergence of poorer region takes place are: *(i)* inducing foreign direct investment in low and middle income regions and *(ii)* increasing the regions' exports. According to our understanding, in the CAM model this will come about mainly by 'directly modelling' an increase in the export market shares of the respective region. The topic of our paper – technology and human capital – is linked to these activities in the sense that advances in technology should induce more investment in *physical* capital which in turn increases the export base.[9]

We relate the insights from this paper to the individual scenarios using the following three factors:

- Relevant technological frontier
- Investment in education and human capital
- Free flow of technology spillovers

Consolidation Scenario

In this scenario the relevant technological frontier is global in scope. Multinational firms continue to operate globally with foreign direct investment (FDI) flowing to most profitable markets (with acceptable political risk). Also, the trade flows between major trading partners and emerging markets will continue to intensify as remaining tariff and non-tariff barriers will be further reduced or entirely dismantled. The promotion of convergence among countries will be less of an issue as civil society organisations (CSO) and social movements will not be influential enough to induce or lobby for supportive measures (partly because government will also save on expenditure for CSOs).

This scenario may be beneficial for emerging regions which are already involved in trade in manufactures and also target markets for FDI as the channels for technology flows remain open. On the other hand little efforts are made to involve marginalised countries that are far behind the technological frontier and that also lack locational attractiveness therefore receiving only little amounts of FDI.

Investment in education and human capital will not be a high priority in this scenario. The cuts in public expenditures characterising this scenario will negatively affect investment in education slowing down or even halting the global upward trends in educational attainments (such as years of schooling, school enrolment rates,…). However, to the extent that the consolidation scenario only

[9] Investment in human capital could be reflected in government spending.

foresees reductions in public expenditures in developed countries, the existing gaps in educational attainments between low and middle income countries and developed countries may be reduced. Factors that could counteract a potential convergence in human capital are that development aid, including aid for education, will be reduced and that in developed countries the private sector may more readily compensate reductions in educational investments than in low income countries.

Most problematic from the perspective of technology catch-up in this scenario could be that knowledge flows and technology spillovers are hampered by institutional factors. More precisely, we mean the design the intellectual property right regimes. Obviously, the longer is the duration of patent protection and the lower are the novelty requirements for innovations the more likely it is that the free flow of spillovers are curtailed. As the this scenario assumes that multinational companies have a big say in forging international trade, investment and intellectual property rules, strong protectionism in this area is to be expected. Moreover, as the scenario implies further liberalisation of international investments, banning ownership restrictions, foreign direct investment may more often take the form of wholly owned subsidies instead as joint-ventures with local firms.

Bipolar Scenario

The current description of the bipolar scenario does not make any statement on whether convergence promotion will be an issue. On the one hand, China and the US will be mainly concerned with the welfare of their own countries. On the other hand, if the scenario is envisaged to be not fully harmonic but entail a great deal of rivalry – the most plausible case – then both the US and China will try to support strategically important countries. In this respect we could envisage the bipolar scenario as being similar to the situation that prevailed during the period of the Cold War but replacing the U.S.S.R with China. Moreover, we would assume that Europe manages to "stay neutral" in this situation and is capable to remain friendly relationships with both the US and China. This scenario could also foresee an R&D race between the US and China.

In this framework the relevant technological frontier could be seen as 'semi-global' with countries in the sphere of influence of the USA drawing on the US technology and allied countries and countries in the Chinese sphere of influence drawing on the Chinese technological frontier. This would imply that US multinationals mainly invest in 'allied countries or regions' (presumably Other Developed Countries, Central America and South America) and also that trade relations will be tightened with those regions. A similar situation prevails for China which will be active mainly in Asian regions and Africa. An important (dividing) issue in this context could be the definition of product standards which each of the two major Blocs following their own (non-compatible) standards.

In this scenario investment in education and innovation will be a major issue as both the US and China will strive for the technological lead in major industries (e.g. automotive, aerospace, nano-electronics and environmental technologies) and science in general. Expenditures in R&D – which are rapidly increasing in China – could experience a boost, partly offsetting the fact that a 'global technological frontier' ceases to exist.

In a bipolar world, the US and China will presumably provide bilateral development assistance to allied countries and regions, in particular to countries that are deemed geo-strategically important. Development assistance may take the form of direct grants and military support (e.g. provision of arms) but 'aid for education' will probably not be very high on the agenda (the US are traditionally the donor country with the smallest share of education aid in total aid provided).[10]

The exchange of technologies will be stronger within the partners of the respective spheres of influence and they will also be fewer barriers to such technology flows. Intellectual property rights could be one of the controversial issues in the bipolar scenario. The US will demand increasingly strong protection of intellectual property. China's position on this issue could be selective as it will continue to be dependent on foreign technologies but at the same time may get interested in protection of its own patents and copyrights.

Multipolar Scenario

In the multipolar world countries can draw on the global technological frontier. Income convergence and technological catching-up is an issue in global governance, and particularly in global trade and investment negotiations.

In this scenario the optimistic view that all countries can overcome existing poverty traps in human capital prevails. National education programmes could be supported by educational aid programmes the budget of which will increase significantly as Official Development Assistance will finally reach the long term target of 0.7% of GDP of donor countries. In middle income countries such educational programmes could, for example, take the form of One Laptop per Child (OLPC)-type of projects where the international donor community would cover the costs for the computers, training and maintenance.[11] Ideally, such projects are designed like the Indian Sakshat programmes where the low-cost tablet computers for children are also produced in India.

Technology flows from developed regions to low and middle income regions are explicitly supported by stronger co-operations in the field of research and in-

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[10] In the period 2001-2002 aid to education amounted to only 3.6% of total aid provided by the US, whereas for New Zealand the share was more than a third.

[11] In Uruguay such a programme (Plan Ceibal; Education Connect) has started and was fully implemented by October 2009 involving 362,000 pupils and 18,000 teachers. The cost to the state is reported at $260 per child, including maintenance costs, equipment repairs, training for the teachers and internet connection. The annual cost of maintaining the programme, including an information portal for pupils and teachers, will be US$21 per child. See http://en.wikipedia.org/wiki/One_Laptop_per_Child.

vestment in human capital. The World Intellectual Property Organisation (WIPO) will set global standards for patents and other trademark laws, including less generous provisions on the maximum duration of patent protections. Moreover, developed countries may agree to renounce on intellectual property rights on chemical substances, including pharmaceuticals, boosting access to technology in the field of agriculture, health and others areas.

The reduction in patent protection reduces the incentive to undertake R&D, above all in developed countries. This impact, however, need not be very large as innovators still benefit from their innovations due to the imitation lag, reputational advantages and the head start in reducing production costs from through learning effects. Moreover, R&D will receive increased public funding. Governments will also –pushed by CSOs – increasingly adopt open source software. This will provide a great stimulus to the development of open source software.

International investment rules will be flexible for low income countries to give them sufficient policy space. In particular, ownership restrictions in FDI projects are possible and implemented to foster joint-ventures between multinationals and local firms. At the same time such restrictions tend to reduce the amount of FDI received.

Regionalisation Scenario

In the regionalisation scenario the relevant technological frontier is assumed to be mainly regional in scope. This is because the deadlock at the multilateral stage along with intensification of regional integration processes (EU, ASEAN, NAFTA, MERCOSUR) will strengthen regional trade and investment flows, even if the scenario takes the form of an "open regionalism". Convergence is an issue, primarily at the regional level. For a limited group of countries, i.e. the East European region and Other East Asia may benefit most in a regionalisation scenario with respect to spillovers as their main trading partners and sources of such spillovers are within their (wider) region. For regions that do not include technology leaders or only very few (i.e. Africa South, Africa North, West Asia, India and Other South Asia as well as the CIS region).

Explicit efforts to improve educational systems will be institutionalised only in the EU which could extend this to selected neighbourhood regions (Africa North, non-EU East Europe). In all other regions developments would rather resemble the baseline scenario.

Regional technology flows will be supported by the setting of common technological standards, facilitating trade and investment flows. Moreover within the EU a single European Union-wide patent system could finally emerge. Within the regional Blocs that are successful in their integration efforts (mainly NAFTA, the EU and ASEAN +JA, CN, EAH) there will also be increased international R&D co-operation both between public institutions and between firms. Moreover, supranational institutions may also implement (or increase) funding for R&D and explicitly foster co-operations.

7 Conclusions

In this paper we clustered countries into three distinct groups of countries on the basis of their innovative and absorptive capacities. In line with theoretical models of technology clubs we termed these clusters innovation club, imitation club and stagnation club. There are large differences in the mean values of the innovation and absorptive capacity (human capital) variables used in the cluster analysis. The differences are particularly pronounced in the human capital variable when comparing the stagnation and the imitation group. Along the R&D dimension the differences are larger between the innovation and the imitation groups.

In the growth regression framework we introduce the idea of technology clubs by letting the strength of the catch-up effects vary with the level of human capital – our proxy for absorptive capacity. We do this by allowing for thresholds in the human capital variable. Hence, the threshold regression technique adds a further dimension by allowing different coefficients for the catch-up term for different groups of countries, with the thresholds that distinguish the groups being determined by the data. The results from the threshold regressions suggest that the growth effects from the catch-up variable are strongest for countries with an intermediate level of human capital. In contrast, countries with very low levels of absorptive capacity benefit to a much lesser extent from such catch-up effects. This result supports the idea of technology clubs, implying that there could be a group of countries that fail to catch-up due to initially unfavourable conditions and the inability to absorb foreign technologies.

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Appendix

Table A1. List of countries in cluster analysis

World Bank code	Country	World Bank code	Country	World Bank code	country
AFG	Afghanistan	GUY	Guyana	NOR	Norway
ALB	Albania	HKG	Hong Kong SAR, China	NPL	Nepal
ARE	United Arab Emirates	HND	Honduras	NZL	New Zealand
ARG	Argentina	HRV	Croatia	PAK	Pakistan
ARM	Armenia	HTI	Haiti	PAN	Panama
AUS	Australia	HUN	Hungary	PER	Peru
AUT	Austria	IDN	Indonesia	PHL	Philippines
BDI	Burundi	IND	India	PNG	Papua New Guinea
BEL	Belgium	IRL	Ireland	POL	Poland
BEN	Benin	IRN	Iran, Islamic Rep.	PRT	Portugal
BGD	Bangladesh	IRQ	Iraq	PRY	Paraguay
BGR	Bulgaria	ISL	Iceland	QAT	Qatar
BHR	Bahrain	ITA	Italy	ROM	Romania
BLZ	Belize	JAM	Jamaica	RUS	Russian Federation
BOL	Bolivia	JOR	Jordan	RWA	Rwanda
BRA	Brazil	JPN	Japan	SAU	Saudi Arabia
BRB	Barbados	KAZ	Kazakhstan	SDN	Sudan
BWA	Botswana	KEN	Kenya	SEN	Senegal
CAF	Central African Republic	KGZ	Kyrgyz Republic	SGP	Singapore
CAN	Canada	KHM	Cambodia	SLE	Sierra Leone
CHE	Switzerland	KOR	Korea, Rep.	SLV	El Salvador
CHL	Chile	KWT	Kuwait	SRB	Serbia
CHN	China	LAO	Lao PDR	SVK	Slovak Republic
CIV	Cote d'Ivoire	LBR	Liberia	SVN	Slovenia
CMR	Cameroon	LBY	Libya	SWE	Sweden
COG	Congo, Rep.	LKA	Sri Lanka	SWZ	Swaziland
COL	Colombia	LSO	Lesotho	SYR	Syrian Arab Republic
CRI	Costa Rica	LTU	Lithuania	TGO	Togo
CUB	Cuba	LUX	Luxembourg	THA	Thailand
CYP	Cyprus	LVA	Latvia	TJK	Tajikistan
CZE	Czech Republic	MAC	Macao SAR, China	TON	Tonga
DEU	Germany	MAR	Morocco	TTO	Trinidad and Tobago
DNK	Denmark	MDA	Moldova	TUN	Tunisia
DOM	Dominican Republic	MDV	Maldives	TUR	Turkey
DZA	Algeria	MEX	Mexico	TZA	Tanzania
ECU	Ecuador	MLI	Mali	UGA	Uganda
EGY	Egypt, Arab Rep.	MLT	Malta	UKR	Ukraine
ESP	Spain	MMR	Myanmar	URY	Uruguay
EST	Estonia	MNG	Mongolia	USA	United States
FIN	Finland	MOZ	Mozambique	VEN	Venezuela, RB
FJI	Fiji	MRT	Mauritania	VNM	Vietnam
FRA	France	MUS	Mauritius	YEM	Yemen, Rep.
GAB	Gabon	MWI	Malawi	ZAF	South Africa
GBR	United Kingdom	MYS	Malaysia	ZAR	Congo, Dem. Rep.
GHA	Ghana	NAM	Namibia	ZMB	Zambia
GMB	Gambia, The	NER	Niger	ZWE	Zimbabwe

GRC	Greece	NIC	Nicaragua
GTM	Guatemala	NLD	Netherlands

Table A2. Cluster results for individual countries

rep	country	augur region	club	R&D expenditure (% of GDP)	literacy rate (in %)	average years of schooling
South East and East Asia						
-						
JPN	Japan	JA	innovation	3.39	99.00	11.26
MAC	Macao SAR, China	CN	immitation	0.11	93.50	7.50
CHN	China	CN	immitation	1.40	94.00	7.62
HKG	Hong Kong SAR, China	EAH	immitation	0.80	94.60	9.86
SGP	Singapore	EAH	innovation	2.36	94.70	8.47
KOR	Korea, Rep.	EAH	innovation	3.00	99.00	11.47
TON	Tonga	EAO	immitation	0.30	99.00	10.40
PHL	Philippines	EAO	immitation	0.12	95.40	8.62
IDN	Indonesia	EAO	immitation	0.05	92.10	5.73
THA	Thailand	EAO	immitation	0.24	93.50	6.83
MNG	Mongolia	EAO	immitation	0.23	97.50	7.95
VNM	Vietnam	EAO	immitation	0.40	92.80	5.75
MYS	Malaysia	EAO	immitation	0.64	92.50	9.68
FJI	Fiji	EAO	immitation	0.25	94.40	10.98
MMR	Myanmar	EAO	immitation	0.20	92.00	4.15
PNG	Papua New Guinea	EAO	stagnation	0.25	60.10	4.53
LAO	Lao PDR	EAO	stagnation	0.20	72.70	4.65
KHM	Cambodia	EAO	stagnation	0.20	77.60	5.90
Europe						
-						
LUX	Luxembourg	EUC	innovation	1.65	99.00	9.85
CHE	Switzerland	EUC	innovation	3.00	99.00	9.65
NLD	Netherlands	EUC	innovation	1.73	99.00	10.81
DEU	Germany	EUC	innovation	2.52	99.00	11.84
AUT	Austria	EUC	innovation	2.53	99.00	9.32
FRA	France	EUC	innovation	2.07	99.00	9.88
BEL	Belgium	EUC	innovation	1.88	99.00	10.47
ROM	Romania	EUE	immitation	0.50	97.70	10.07
ALB	Albania	EUE	immitation	0.45	95.90	10.28
BGR	Bulgaria	EUE	immitation	0.49	98.30	9.71
HRV	Croatia	EUE	immitation	0.84	98.80	8.71
SRB	Serbia	EUE	immitation	0.41	96.40	9.03
HUN	Hungary	EUE	immitation	0.97	99.40	11.49
SVK	Slovak Republic	EUE	immitation	0.48	99.00	11.10
POL	Poland	EUE	immitation	0.58	99.50	9.68
CZE	Czech Republic	EUE	innovation	1.49	99.00	12.75
SVN	Slovenia	EUE	innovation	1.53	99.70	8.69
FIN	Finland	EUN	innovation	3.47	99.00	9.78
DNK	Denmark	EUN	innovation	2.56	99.00	9.87
NOR	Norway	EUN	innovation	1.58	99.00	12.34
SWE	Sweden	EUN	innovation	3.68	99.00	11.50
PRT	Portugal	EUS	immitation	1.14	94.90	7.60
MLT	Malta	EUS	immitation	0.59	92.40	9.99
ESP	Spain	EUS	immitation	1.23	97.73	9.72
CYP	Cyprus	EUS	immitation	0.44	97.90	9.27
ITA	Italy	EUS	immitation	1.15	98.90	9.15
GRC	Greece	EUS	immitation	0.57	97.20	9.89

IRL	Ireland	EUS	innovation	1.30	99.00	11.25
ISL	Iceland	EUS	innovation	2.78	99.00	10.11
GBR	United Kingdom	EUW	innovation	1.80	99.00	9.21

Table A2. Cluster results for individual countries (continued)

rep	country	augur region	club	R&D expenditure (% of GDP)	literacy rate (in %)	average years of schooling
Americas and Euroepan Offsprings						
USA	United States	US	innovation	2.70	99.00	12.09
CHL	Chile	AM	immitation	0.60	98.60	9.71
COL	Colombia	AM	immitation	0.16	92.88	7.05
BOL	Bolivia	AM	immitation	0.60	90.70	9.36
PRY	Paraguay	AM	immitation	0.09	94.60	7.60
ECU	Ecuador	AM	immitation	0.15	84.20	7.65
URY	Uruguay	AM	immitation	0.47	98.05	7.99
VEN	Venezuela, RB	AM	immitation	0.60	95.20	6.40
ARG	Argentina	AM	immitation	0.49	97.70	9.13
PER	Peru	AM	immitation	0.60	88.73	8.68
BRA	Brazil	AM	immitation	1.02	89.87	7.17
MEX	Mexico	ACX	immitation	0.39	92.48	8.39
DOM	Dominican Republic	ACX	immitation	0.60	88.20	7.01
JAM	Jamaica	ACX	immitation	0.60	86.40	9.62
BLZ	Belize	ACX	immitation	0.60	75.10	9.34
TTO	Trinidad and Tobago	ACX	immitation	0.09	98.70	9.30
CUB	Cuba	ACX	immitation	0.46	99.80	10.14
SLV	El Salvador	ACX	immitation	0.09	83.43	7.34
GUY	Guyana	ACX	immitation	0.60	99.00	8.21
NIC	Nicaragua	ACX	immitation	0.60	78.00	6.07
CRI	Costa Rica	ACX	immitation	0.36	96.10	8.05
PAN	Panama	ACX	immitation	0.23	93.60	9.29
HND	Honduras	ACX	immitation	0.60	83.60	6.83
BRB	Barbados	ACX	immitation	0.60	99.70	9.34
HTI	Haiti	ACX	stagnation	0.20	48.70	4.84
GTM	Guatemala	ACX	stagnation	0.05	74.50	3.99
AUS	Australia	OD	innovation	2.06	99.00	11.87
CAN	Canada	OD	innovation	1.94	99.00	11.23
NZL	New Zealand	OD	innovation	1.19	99.00	12.44
South Asia & CIS						
IND	India	IN	stagnation	0.80	62.80	4.68
MDV	Maldives	ASO	immitation	0.20	98.40	5.14
LKA	Sri Lanka	ASO	immitation	0.17	90.70	8.29
AFG	Afghanistan	ASO	stagnation	0.10	28.00	3.53
PAK	Pakistan	ASO	stagnation	0.56	53.20	4.92
BGD	Bangladesh	ASO	stagnation	0.20	55.90	5.20
NPL	Nepal	ASO	stagnation	0.20	59.10	3.38
TJK	Tajikistan	CI	immitation	0.09	99.70	9.32
LVA	Latvia	CI	immitation	0.62	99.80	10.20
KGZ	Kyrgyz Republic	CI	immitation	0.22	99.20	8.57
LTU	Lithuania	CI	immitation	0.79	99.70	10.38
UKR	Ukraine	CI	immitation	0.94	99.70	10.87

MDA	Moldova	CI	immitation	0.45	98.50	9.39
KAZ	Kazakhstan	CI	immitation	0.24	99.70	10.11
RUS	Russian Federation	CI	immitation	1.07	99.60	9.56
ARM	Armenia	CI	immitation	0.22	99.50	10.39
EST	Estonia	CI	innovation	1.12	99.80	11.57

Table A2. Cluster results for individual countries (continued)

rep	country	augur region	club	R&D expenditure (% of GDP)	literacy rate (in %)	average years of schooling
Africa and West Asia						
TUN	Tunisia	AFN	immitation	1.02	77.60	6.58
DZA	Algeria	AFN	immitation	0.07	72.60	7.18
LBY	Libya	AFN	immitation	0.30	88.90	7.24
SDN	Sudan	AFN	stagnation	0.29	70.20	3.04
EGY	Egypt, Arab Rep.	AFN	stagnation	0.25	68.90	6.59
MAR	Morocco	AFN	stagnation	0.64	55.60	4.41
SWZ	Swaziland	AFS	immitation	0.30	86.90	7.32
NAM	Namibia	AFS	immitation	0.30	88.50	7.39
GAB	Gabon	AFS	immitation	0.30	87.70	7.65
BWA	Botswana	AFS	immitation	0.50	84.10	9.27
ZAF	South Africa	AFS	immitation	0.93	88.70	8.26
MUS	Mauritius	AFS	immitation	0.37	87.90	7.32
KEN	Kenya	AFS	immitation	0.30	87.00	7.10
LSO	Lesotho	AFS	immitation	0.20	89.70	6.04
ZWE	Zimbabwe	AFS	immitation	0.30	91.90	7.48
TZA	Tanzania	AFS	stagnation	0.20	72.90	5.05
SEN	Senegal	AFS	stagnation	0.09	45.80	4.67
MWI	Malawi	AFS	stagnation	0.30	73.70	4.37
BDI	Burundi	AFS	stagnation	0.30	66.60	2.86
MRT	Mauritania	AFS	stagnation	0.30	57.50	4.08
BEN	Benin	AFS	stagnation	0.20	41.70	3.64
GHA	Ghana	AFS	stagnation	0.30	66.60	7.50
GMB	Gambia, The	AFS	stagnation	0.20	46.50	3.07
CMR	Cameroon	AFS	stagnation	0.30	70.70	5.75
ZMB	Zambia	AFS	stagnation	0.03	70.90	6.33
CAF	Central African Repub-lic	AFS	stagnation	0.20	55.20	3.49
CIV	Cote d'Ivoire	AFS	stagnation	0.30	55.30	3.57
COG	Congo, Rep.	AFS	stagnation	0.30	67.20	5.93
RWA	Rwanda	AFS	stagnation	0.20	70.70	3.61
SLE	Sierra Leone	AFS	stagnation	0.20	40.90	3.07
TGO	Togo	AFS	stagnation	0.20	56.90	5.42
UGA	Uganda	AFS	stagnation	0.30	73.60	4.86
MOZ	Mozambique	AFS	stagnation	0.53	55.10	1.24
NER	Niger	AFS	stagnation	0.20	28.70	1.54
MLI	Mali	AFS	stagnation	0.20	26.20	1.54
LBR	Liberia	AFS	stagnation	0.30	59.10	4.25
ZAR	Congo, Dem. Rep.	AFS	stagnation	0.48	67.00	3.46
SAU	Saudi Arabia	WA	immitation	0.04	86.10	7.68
IRN	Iran, Islamic Rep.	WA	immitation	0.70	83.23	7.33
QAT	Qatar	WA	immitation	0.10	93.93	7.22
KWT	Kuwait	WA	immitation	0.09	93.75	6.06
ARE	United Arab Emirates	WA	immitation	0.30	90.00	8.78
JOR	Jordan	WA	immitation	0.10	91.65	8.72
BHR	Bahrain	WA	immitation	0.30	91.40	9.18
TUR	Turkey	WA	immitation	0.63	88.95	6.47
IRQ	Iraq	WA	stagnation	0.30	78.10	5.41
YEM	Yemen, Rep.	WA	stagnation	0.10	62.40	2.96
SYR	Syrian Arab Republic	WA	stagnation	0.10	84.20	4.82

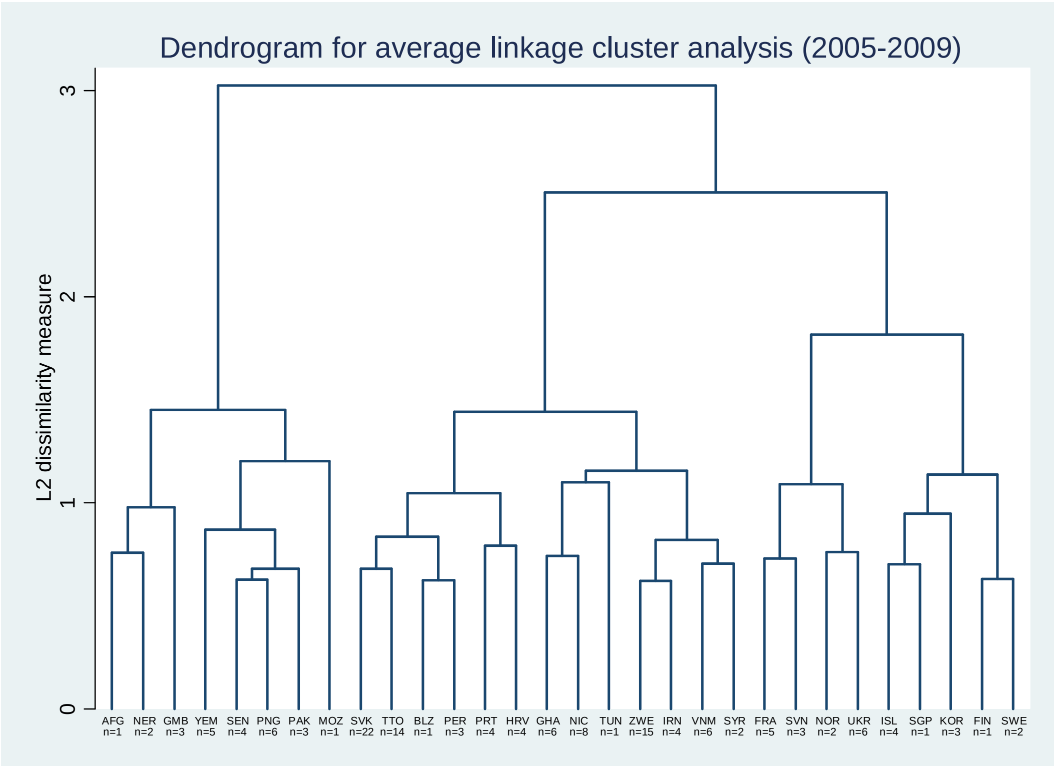
Table A3. List of countries in regression analysis

World Bank code	Country	World Bank code	Country
ARG	Argentina	ITA	Italy
AUS	Australia	JOR	Jordan
AUT	Austria	JPN	Japan
BEL	Belgium	KEN	Kenya
BGD	Bangladesh	KOR	Korea, Rep.
BGR	Bulgaria	LSO	Lesotho
BOL	Bolivia	MAR	Morocco
BRA	Brazil	MEX	Mexico
BWA	Botswana	MLI	Mali
CAN	Canada	MLT	Malta
CHE	Switzerland	MOZ	Mozambique
CHL	Chile	MUS	Mauritius
CHN	China	MYS	Malaysia
CIV	Cote d'Ivoire	NAM	Namibia
CMR	Cameroon	NIC	Nicaragua
CRI	Costa Rica	NLD	Netherlands
CUB	Cuba	NOR	Norway
CYP	Cyprus	NZL	New Zealand
DEU	Germany	PAK	Pakistan
DNK	Denmark	PAN	Panama
DZA	Algeria	PER	Peru
ECU	Ecuador	PHL	Philippines
EGY	Egypt, Arab Rep.	PRT	Portugal
ESP	Spain	PRY	Paraguay
FIN	Finland	SDN	Sudan
FRA	France	SEN	Senegal
GAB	Gabon	SLV	El Salvador
GBR	United Kingdom	SWE	Sweden
GRC	Greece	SWZ	Swaziland
GTM	Guatemala	SYR	Syrian Arab Republic
HKG	Hong Kong SAR, China	TGO	Togo
HND	Honduras	THA	Thailand
HUN	Hungary	TUN	Tunisia
IDN	Indonesia	URY	Uruguay
IND	India	USA	United States
IRL	Ireland	VEN	Venezuela, RB
IRN	Iran, Islamic Rep.	ZAF	South Africa
ISL	Iceland	ZMB	Zambia

Table A4. Pseudo-F values from Calinski-Harabasz method for determining the number of clusters

Number of clusters	Calinski/ Harabasz pseudo-F
2	102.74
3	166.89
4	140.82
5	117.70
6	175.53
7	149.05
8	157.73
9	145.53
10	131.96
11	131.05
12	140.45
13	133.67
14	129.31
15	129.98

Figure A1. Dendrogram for average linkage cluster analysis (2005-2009)



Note: Only upper part of cluster tree is shown.

Table A5. Pseudo-F values from Calinski-Harabasz method from non-hierarchical cluster analysis with alternative numbers of resulting clusters

Number of clusters	Calinski/ Harabasz pseudo-F
3	200.52
4	201.76
5	191.92
6	168.02