# Winning or losing a run: the role of technological drivers at stages of development

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**Abstract**

This article studies the role of technology drivers in catching up at different stages of development. Countries can be at different stages of development when entering in a new catching-up cycle. Thus, the technological drivers of growth [technological capabilities, external spillovers, technological specialization and stability of policies in science and technology] can play different roles to accelerate the rate of growth and change their relative position in the leadership rank (win or lose the run).

The empirical results show the building of a 'racing pattern' as countries climb up development stages. At earlier stages, infrastructures and qualification play a major role, while at upper stages, the maintenance of leadership depends on accumlating techno-scientific capabilities to innovate. The article also finds that R&D is crucial at any stage of development, as well as the stability of technology policies.

**Resumen**

Este artículo estudia el papel del cambio tecnológico sobre el proceso de *catching-up* en diferentes estadios de desarrollo. El trabajo asume que los países pueden encontrarse en diferentes estadios de desarrollo cuando entran en un nuevo ciclo de *catching up*. En este sentido, los ‘conductores’ tecnológicos del crecimiento (las capacitaciones internas, los *spillovers* externos, la especialización tecnológica y la estabilidad de las políticas en ciencia y tecnología) pueden jugar un papel diferente como aceleradores del ritmo de crecimiento y cambiar la posición relativa de un país en el ranking del liderazgo mundial (ganar o perder a carrera).

Los resultados muestran que existe un cierto patrón acerca de la importancia de los ‘conductores del crecimiento’ a medida que el proceso de desarrollo va pasando a estadios más avanzados. En los estadios más tempranos, las infraestructuras y la cualificación de la fuerza de trabajo juegan un papel central, mientras que en estadios superiores, el liderazgo se sustenta por el mantenimiento de la capacidad de innovar. El artículo muestra también que la I+D es crucial en cualquier estadio del desarrollo, así como la estabilidad de las políticas tecnológicas.

**Highlights**

- Growth and catching up are linked and both are cyclic and asymmetric across countries.
- The divergence in technology drivers of growth are growing at lower stages of development.
- Different technological drivers of growth plays a different role by stages of growth and catching-up cycles.
- Technological capacitation and the stability of technology policies are the most important drivers at any stage of growth and catching up.

*Keywords:* Catching up, Technological Drivers, Growth, Stages of growth, Development, World.

*Palabras clave:* Catching-up, conductores tecnológicos, crecimiento, estadios de crecimiento, desarrollo, mundo.

*JEL Classification:* O11; O40; O50; O33; O38

## Introduction

The occurrence of unequal growth is an old subject in economic literature. The Neoclassical approach addresses this question in the theory of the long-term growth and convergence. C*onvergence* is the process by which countries with lower level of income per capita (delayers) achieve rates of growth faster than countries with higher level of income per capita (leaders). In the long-term equilibrium, Neoclassical models foresee that the growth of per capita income equalizes countries at a unique equilibrium or steady state (Solow classical model) or at multiple equilibria (endogenous growth, clubs of convergence or unified growth theory) (Romer, 1990; Sala-i-Matín, 1996; De la Fuente 2002; Galor, 2010). A higher marginal productivity of capital and the free access to technology give the delayers a greater initial potential to growth. However, as productivity gaps close, the rhythms of economic growth slow down and economies converge. The endogenous growth theory and the theory of convergence clubs introduce the idea of multiple equilibria. In these approaches, differences of historical and structural nature produce different equilibria as countries converge. Thus, only countries with similar structural characteristics would converge to the same equilibrium (per capita income rates of growth) in the long term.

The vision of dynamic equilibria is an alternative approach to steady state. In this Schumpeterian alternative method, the *catching up as a continuous and cyclic process* replaces the concept of *convergence*. Countries are in a run along the process of socio-economic development. The traditional approach for catching-up considers that latecomers have a potential to take a larger growth leaps when introducing frontier technologies through investment in capital goods (Abramovitz, 1986). Capitalization also provides followers the opportunity for modernization in disembodied technologies and the reallocation of resources from low to high productivity industries, which would drive to structural change. Therefore, followers have the chance to break a lock-in situation and change their relative position in the run. Additionally, a country is not a latecomer by accident, but by a set of shortcomings that result from historical conditions. Thus, the achievement of a technological leap demands much more than capitalization. It also requires adaptability of institutions to change, the integration between the social capabilities and technological opportunities to make the technological choice and a set of economic conditions relative to market competition and market structures (Abramovitz, 1994:25).

From a historical perspective, along a process of development (as an evolutionary process), the run for the leadership is dynamic and no equilibrium is achieved. The technological leap can happen in any country and the leadership in terms of productivity gaps will eventually change in the long and in the very long-run. The leadership changes because countries move across cycles of catching up that emerge when a new technological microparadigm arises. The phases of a catching-up cycle are entry, gradual catching-up, forging ahead, and falling behind (Abramovitz, 1986; Landini et al 2017). From a microeconomic point of view, entry and gradual catching up correspond to initial phases of production, when latecomers must overcome their disadvantages to the incumbents to take a new place in the industry. The 'forging ahead' stage means rapid adoption and radical innovations in markets, products, processes and organization, which can transform a latecomer into leader. The final stage corresponds to a falling behind or decline (loss of leadership) due to the emergence of new leaders that have built advantages and taken the opportunities provided by new technological micro paradigms, initializing a new cycle of catching up. This microeconomic dimension allows the analysis of the catching up as a non-linear process where countries not only run in different speeds, but also in different directions, building leaderships in different industries and technologies.

At the macroeconomic level, rank mobility is only observed in very long periods. For example, the alternation in the world hegemony since the beginning of the modern age, since the Spanish Empire, to the French and British Empires; followed by Germany, Russia, United States, Japan; and in our days by the emergence of the Asian tigers and the BRICS. In this sense, it is a stylized fact of growth that technology and productivity gaps tend to remain for long periods and convergence does not happen as neoclassical theory predicted. However, the alternation of the rankings really happens at microeconomic level and uses to be asymmetric by country and concentrated in the more dynamic industries. Recent studies on catching up in emerging countries call attention for the role played by specific industries and firms to initiate a cycle of catching up that, afterwards, extends to other industries through productive and technological spillovers (Lee, 2013).

In light of the above considerations, the objective of this article is to test the role of technological drivers of growth in the catching up cycles at different relative rank positions in the run (stages of development). We assume that: (1) leader countries do not stand at the technological frontier in all technologies and industries, on the contrary, technological frontier is dynamic and defined by the new winners in the technological competition at microeconomic level; (2) to some extent, there is a correspondence between stages of development and cycles of catching up at the macroeconomic level. Once defined the stages of development by country, the article aims to determine which technological driver was more relevant to direct the catching up towards forging ahead or falling behind.

To classify countries by stage of development, we use the idea of 'stage' in Rostow's sense. Each stage of development includes aspects as the evolution of per capita income, the structural change towards high income-elasticity industries, the spread of specific technologies, the qualification of the labor force and the extension of mass consumption of durable goods. A rough solution to the linearity of Rostow's stages is to link the path of economic development to the level of technological development. Castellaci (2011) distinguishes three stages for technological development corresponding to three clustered groups. Stage1 represents the earliest stage of technological development. In this stage, the technological distances from the technological frontier are huge due to very low local technological capacities that prevent the generation and expansion of technologies along an autonomous path of technological development (for example, Less Developed Countries, as most African countries). One could expect that, at this stage, the main category that pushes convergence must be external spillovers given that absorptive capacity and institutional stability are still very low. Stage 2 represents an improved level of technological development where the internal capabilities - communication infrastructures and internal efforts in science and technology- are medium. The distances to the technological frontier in some technologies are high, but latecomers can entry in mature and medium-level technologies. The institutional stability plays a central role to absorb external spillovers and to develop internal efforts to create absorptive capacity. At this stage, technological capabilities and specialization play a major role to catch-up, especially if technological specialization spills over complementary technical knowledge and expands technological development. The smaller the country, the more important the effect of technological specialization. These stage 2 countries are located in peripherical Europe, Asia, in the eighties and, recently, BRICs countries. Stage 3 corresponds to levels of technological development nearby the technological frontier. In this case, countries have high levels of technological capabilities in a wide range of technical fields and maintain productivity gaps across time (for example, United States, Japan or European leaders as Germany). To maintain the leadership, technological specialization can be especially relevant for small countries, as well as external spillovers are quite important for countries geographically located near leaders.

Additionally, we use two indicators: the data of the take-off and the per-capita income between 2005 and 2010. The three criteria classify the sample of 41 countries in four stages. Stage 1 groups a significant number of emerging countries with per capita GDP below US$13,000 that initiated the take-off after 1930. The only exception in this group is Saudi Arabia, which presents a very high per capita GDP (US$ 63,334) strongly linked to oil and gas rents. The insufficient technological performance and maturity of its development process does not permit to include this country out of this group. Stage 2 contains developed countries that made a take-off between 1870 and 1830 but, due to historical reasons, they present medium technological performance and level per capita of GDP (between US$ 15,000 and 30,000). There are three exceptions in this group, New Zealand, Israel and South Korea. Those countries initiated the take-off later, after 1930, but they accelerated their catching up by following a forging ahead behavior in some industries, which place them in a GDP per capita over US$ 25,000. Finally, Stages 3 and 4 includes countries over 30,000 $USA that made the take-off before 1850 (Stage 4) of between 1870 and 1930 (Stage 3) considered leaders in the cluster analysis reported by Castellaci (2011).

**Table 1 – Stages of development for a selected group of countries.**

| STAGE 4 | | STAGE 3 | | STAGE 2 | | STAGE 1 | |
|---|---|---|---|---|---|---|---|
| Country | GDPpc | Country | GDPpc | Country | GDPpc | Country | GDPpc |
| France | 31742,89 | Australia | 40375,58 | Greece | 26642,71 | Argentina | 11346,25 |
| Germany | 33686,75 | Austria | 38331,83 | New Zealand* | 27714,78 | Brazil | 7921,52 |
| United Kingdom | 34571,20 | Belgium | 35450,01 | Portugal | 20105,89 | Chile | 12050,58 |
| United States | 42248,37 | Canada | 37275,86 | Russian Fed. | 14469,97 | Cuba | 10902,27 |
| | | Denmark | 35029,55 | Spain | 28493,12 | Mexico | 12046,14 |
| | | Finland | 33879,70 | Hungary | 16918,66 | China | 6520,48 |
| | | Iceland | 40694,36 | Poland | 15524,85 | India | 3046,56 |
| | | Ireland | 38807,97 | Israel* | 25221,30 | Thailand | 7638,38 |
| | | Italy | 29394,95 | South Korea* | 25041,87 | Singapore | 5840,13 |
| | | Japan | 31747,08 | | | Malasya | 11436,32 |
| | | Netherlands | 38273,89 | | | Turkey | 10173,60 |
| | | Norway | 50943,23 | | | South Africa | 7389,18 |
| | | Sweden | 35696,14 | | | Bulgaria | 10287,01 |
| | | Switzerland | 39319,63 | | | Saudi Arabia | 63334,24 |
| | | | | | | Romania | 9490,92 |
| Take off before 1850 | | Take off 1870-1930 | | | | Take off after 1930 | |
| Leaders (Castellaci, 2011) | | | | Followers (Castellaci, 2011) | | | |

(*) Take-off after 1933.

GDP pc; Gross Domestic product, per capita, PPP 2005 prices, mean for the period 2006-2010.

Source: PENN World Table. Version 7.1.

## 2. The empirical model and the data sources

The empirical model departs from an aggregate production function:

$$y_{it} = A_{it} k_{it}^{\gamma} \tag{1}$$

Equation (1) is related to a country $i$ at the period t, where $y_{it}$ denotes the aggregate output per worker; $k_{it}$ is the private stock of physical capital per worker and $A_{it}$ represents the level of technical progress. Taking logarithms and differentiating with respect to time, the production function becomes a lineal function expressed as:

$$\frac{\Delta y_i}{y_i} = \frac{\Delta A_i}{A_i} + \gamma \frac{\Delta k_i}{k_i} \tag{2}$$

The technical progress by country *i* $(\Delta A_i / A_i)$ can be disaggregated into four components (Eq. 3): the *internal technological capabilities* (*KC$_i$*) (Castellaci, 2006); the *external spillovers* (*KE$_i$*) (Maurseth, 2001; Camerona *et al*, 2005); the *technological specialization* (*KS$_i$*) (Jungmittag, 2004; Brusoni and Geuna, 2003; Huang and Miozzo, 2004; Vertova, 2001; Urraca-Ruiz and Laguna, 2014); the *stability of science and technology* (S&T) *policies* (*IN$_i$*) (Parente and Prescott, 2005).

$$\Delta A_i / A_i = KC_i + KE_i + KS_i + IN_i \tag{3}$$

The internal capacity of innovation (*KC$_i$*) represents the allocation of technological resources and the absorptive capacity $(\varphi_i)$ given by a multiplicative function of a productivity differential $(y_i - y_f)$, that is the distance to the technological frontier. The absorptive capacity $(\varphi_i)$ is determined by the qualification of human resources by formal education (*HK$_i$*), the technological infrastructures (*TI$_i$*), the assimilation and learning from R&D efforts (*RD$_i$*) and the innovative results (*P$_i$*).

$$KC_i = (y_i - y_f)^{\alpha}.\varphi_i = (y_i - y_f)^{\alpha} HK_i^{\varphi_1}.TI_i^{\varphi_2}.RD_i^{\varphi_3}.P_i^{\varphi_4} \tag{4}$$

External spillovers $(KE_i)$ include the share of external knowledge captured by national efforts by transferring technology from overseas $(\omega_i)$ by imports of high-tech and capital products (*TM$_i$*) and by collaboration with foreign agents such as firms, universities, etc. (*C$_i$*).

$$KE_i = (y_i - y_f)^{\tau}.\omega_i = (y_i - y_f)^{\tau} TM_i^{\omega_1}.C_i^{\omega_2} \tag{5}$$

Technological specialization $(KS_i)$ represents the technological choice and the allocation of resources in a specific path of technological trajectory. There are several ways to introduce this effect in empirical models. Mostly, this kind of specialization refers to R&D intensive industries, pervasive technologies and technologies with elevated technological opportunities, that is, linked to new or recent techno-scientific paradigms. Finally, the fourth component $(IN_i)$ captures the role of the public institutions supporting learning and innovation. Government policies and the central role of the state are widely legitimized and necessary - especially for catching up economies, but also for developed countries- as a risk-taken agent with three aims: to finance, to create opportunities and to socialize the returns of technological progress (risk rewards) in the social system and in further innovation processes (Lazonick and Mazzucato, 2013).

Substituting all the equations and values in (2), we obtain:

$$\Delta y_i / y_i = \varphi_1 lnHK_i + \varphi_2 lnTI_i + \varphi_3 lnRD_i + \varphi_4 lnP_i + \beta\, ln(y_i - y_f) + \omega_1 lnTM_i + \omega_2 lnC_i + \mu S_i + \delta IN_i + \gamma I_i \tag{6}$$

The specification of the equation (6) for a dynamic panel estimation takes the form as follows:

$$\ln y_{i,t} = (1+\beta)\ln y_{i,t-1+}\ \varphi_1 lnHK_{i,t-1} + \varphi_2 lnTI_{i,t-1} + \varphi_3 lnRD_{i,t-1} + lnP_{i,t-1} + \mu_t - \beta lny_{f,t-1} + \omega_1 lnTM_{i,t-1} + \omega_2 lnC_{i,t-1} + \mu S_{i,t-1} + \delta IN_i + \gamma\, I_{i,t-1} + u_{it}$$

(7)

The per capita GDP depends on the lagged level of the qualification or human resources, the technological infrastructures, the time path of assimilation and learning from R&D efforts, the innovative results and the knowledge transferred from abroad.

The econometric exercise uses a panel data for a set of 41 countries along a period that ranges from 1980 to 2010 (see Table 2). The sources of information were CANA dataset for most of the technological indicators (Castellacci and Natera, 2011); the European Patent Office, COMTRADE, Penn World Tables 7.1 and World Bank.

*Capacity of innovation* ($KC_i$) is approached using three alternative variables; patents stocks (*PSK*), R&D expenditures as a percentage of GDP (RD) and scientific articles (*SAR*). There are five selected indicators for measuring *human capital*: school enrolment for primary, secondary and tertiary education (*HK1; HK2* and *HK3* respectively); public expenditure in education (*HK4*) and mean years of schooling (*HK5*). Six indicators approximate *communication infrastructures*: telecommunications revenue (*TI1*), mobile and fixed-line subscribers (*TI2*), internet users per 1000 inhabitants (*TI3*), paved roads as percentage of the country's total road length (*TI4*) and registered carrier departures worldwide (*TI6*).

Two indicators measure *external spillovers* ($KE_i$). The first one takes the spillovers coming from embodied technologies in imports of machinery and transport (*TM*). The second one captures knowledge flows from transnational cooperation, collaboration and internationalization (*TRANSFER*) and it is measured as the share of patents with more than one residence-country among the applicants over the total patents applied by a country.

**Table 2. Variables definition**

| | | Source | Variable definition |
|---|---|---|---|
| **INTERNAL TECHNOLOGICAL CAPABILITIES** | GDP pc: Per capita Gross Domestic Product | PENN World Table 7.1 | Per capita Gross Domestic Product in PPP at 2005 constant prices |
| | k: Per capita investment share | PENN World Table 7.1 | Per capita investment share in PPP at 2005 prices |
| | RD: R&D expenditures | CANA (UNESCO, OECD, RICYT) | R&D expenditures as a percentage of GDP |
| | SAR: Scientific and technical journal articles | World Bank; National Science Foundation | Number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences, per million people. |
| | PSK: Patent stocks | EPO | Patent stocks with no depreciation rate |
| | HK1: Gross Enrolment Ratio, Primary | UNESCO | Ratio of total enrolment, regardless of age, to the population of the age group that officially corresponds to the primary level. |
| | HK2: Gross Enrolment Ratio, Secondary | UNESCO | Ratio of total enrolment, regardless of age, to the population of the age group that officially corresponds to the secondary level. |
| | HK3: Gross Enrolment Ratio, Tertiary | UNESCO | Ratio of total enrolment, regardless of age, to the population of the age group that officially corresponds to the tertiary level. |
| | TI 1: Telecommunications revenue | CANA | Revenue from the provision of telecommunications services such as fixed-line, mobile, and data, % of GDP. |
| | TI2: Mobile and fixed-line subscribers | CANA | Total telephone subscribers (fixed-line plus mobile) per 1000 inhabitants. |
| | TI3: Internet users per 1000 people | CANA | People with access to the worldwide web network divided by the total amount of population. |
| | TI4: Electric power consumption. | CANA | Production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants. |
| | TI5: Paved Roads. | CANA | Paved roads are those surfaced with crushed stone (macadam) and hydrocarbon binder or bituminized agents, with concrete, or with cobblestones, as a percentage of the whole roads' length of the country. |
| | TI6: Registered carrier departures worldwide | CANA | Domestic take-offs and take-offs abroad of air carriers registered in the country, per 1000 inhabitants. |
| **EXTERNAL SPILLOVERS** | TM: transfer of embodied technology | COMTRADE | Imports of Machinery and transport equipment SITC 2 Rev. Cap 7 (current US$) |
| | TRANSFER: transfer of disembodied technology | EPO | Percentage of patents with applicants or inventors with more than one residence country |
| | | **Source** | **Variable definition** |
| **TECHNOLOGICAL SPECIALIZATION** | SDYN: Dynamic specialization | EPO | Normalized RTA in technologies that registered rates-of-growth above mean between two consecutive periods (see Annex) |

| | | | |
|---|---|---|---|
| | SST1: R&D industries specialization | EPO | Normalized RTA in technologies that corresponding with R&D intensive sectors (see Annex) |
| | SST2: Dynamic technological opportunity specialization | EPO | Normalized RTA in technologies that registered rates-of-growth above mean between initial (1980-85) and final (2005-09) periods. (See Annex) |
| | SST3: Pervasive technologies specialization | EPO | Normalized RTA in pervasive technologies (see Annex) |
| | *Dj*: Technological diversification | EPO | Normalized Diversification index |
| **STABILITY OF S&T POLICIES** | SCSTAB: Stability of the science policy | EPO | Percentage of patents whose applicants are universities, foundations and research institutes |
| | TECHSTAB: Stability of technology policy | EPO | Percentage of patents whose applicants are Government-owned corporations |

The model considers static and dynamic measures for *technological specialization variables* ($KS_i$). Static measures (*SST1*, *SST2, SST3*) are Normalized Revealed Technological Advantages (NRTA) in 'correct technologies' at a national level, given by $NRTA_j = {(p_{kj}/p_{kw}) + 1}\Big/{(p_{kj}/p_{kw}) - 1}$ , where, $p_{kj}$ is the j-country share of *extended patents*[1] in *k-correct technical fields* and $p_{kw}$ is the share of extended patents in the same *k-correct* technical fields for the area of reference. *SST1* defines as *correct* the technologies linked to R&D intensive sectors; *SST2,* technologies that reported patents share rates of growth above the mean between the first period (1981-1985) and the last one (2006-2010); and *SST3* pervasive technologies (see Annex). The dynamic measure of technological specialization (*SDYN*) is a *j-country* NRTA in the *t-period,* in technologies with positive patent share rates of growth between *t* and *t+1.*

The model incorporates also a diversification index $\Big[SSMTH =$ *(1−i=1msij2)1−(1M)*, where $s_{ij}$ is the distribution of the patents share by *i*-technical field in the *j*-country and *M* is the number of technical fields (M=30).

Finally, two indicators capture the impact of the *stability of S&T policy* ($IN_i$). The first one is the stability of science policy (*SCSTAB*), measured as the contribution of public and private foundations, universities, research institutes and government agencies to the total patents applied by residents in a country. The second one is the stability of technology policy (*TECHSTAB*), which takes the contribution of corporations controlled by Government to the total patents applied by residents in a country.

All the variables refer to four-year periods from 1981 to 2009, forming a panel data with 7 periods and 41 countries. The variable *SDYN* only is available for a temporal dimension of six periods, because there is no data available to know which technologies were dynamic after 2009.

## 3. The asymmetric evolution of technology drivers

This section presents the cross-country asymmetries in the evolution of the technology drivers. To do that, we calculate four traditional indicators: *β-convergence*; *Q-convergence*; σ-*convergence* and *cluster-convergence.*

Absolute *β-convergence* is the β parameter in the equation:

$$a - \beta TD_{i,0} + u_{it}, \tag{8}$$

Where $\Delta TD_{i,t}/TD_{i,t}$ is the rate of growth of each technology driver and $TD_{i,0}$ is its initial value. A negative sign of *β-convergence* means that the delayers grew faster than the leaders,

[1] Each patent represent a set of technological competences in all the different technical fields that it contains at a 4-digit level of aggregation (IPC4D). The number of observations was expanded including all the technical fields where a country was technologically active. The 650 technical fields (IPC4D) were grouped into 30 technical fields to calculate the specialization variables (see Annex).

and therefore, the countries converged, and the asymmetries became lower. The results reveal a pattern of β-convergence in all the indicators of the four drivers, showing a highest speed of convergence in technological specialization, transfer of disembodied technologies, and, to a lesser extent, in the enrolment ratio for tertiary education (Table 3). Convergence in specialization patterns means that countries moved to the same technologies. The high speed of convergence in the transfer of disembodied technology reflects the widespread inclusion of follower countries in the geography of technological internationalization.

The Q-convergence is a β-convergence regressed by quantiles (Castellacci, 2011). Quantiles are groups sorted from the lowest to the highest rates of growth for each variable in each technology driver. Hence, the first quantile (20th) represents the 20% of the countries of the sample that experienced the lowest rates of growth. As upper quantiles include countries with higher rates of growth, an increasing speed of convergence means that the latter group (more dynamic) had a worse initial situation and, therefore, convergence and the reduction of the asymmetries took place. The speeds of convergence among technology drivers are quite smaller at the lower quantiles, but it accelerates in upper quantiles, achieving even higher values than the λ-value for β-convergence when 80% of the distribution is included. Three of the variables for technological capability, -R&D expenditures, scientific articles and enrollment in tertiary education-, show a speed of convergence more moderated than β-convergence. The β-coefficients of the regressions for the embodied technology transfer and the stability of S&T policies were not statistically significant (Table 3).

The σ-convergence provides a dispersion measure across countries between an initial ($t_0$) and an ending ($t_1$) period. A negative sign in the rate of growth indicates a decreasing dispersion among technology drivers. In the final period, there is less variability across countries although it remains large for the Patent stocks variable and the Embodied technology transfer. The higher values are relative to Mobile and fixed-line subscribers; Internet users per 1000 people; Technological diversification and Stability of the science policy. Dispersion remains almost constant in Telecommunications revenue and it shows just a small decrease in Patent stocks variable. Finally, Embodied technology transfer and the Stability of technology policies presented increasing dispersion.

**Table 3. Convergence measures for gaps in technology drivers**

| | ***Absolute β-convergence*** | | | ***Conditioned Q-convergence*** **(λ)** | | | | ***σ-convergence*** | | | ***Cluster convergence*** **(b)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **β** | **t-value** | **λ** | **20th** | **40th** | **60th** | **80th** | **(a) $t_0$** | **(a) $t_1$** | **(c)** | **S4-S3** | **S3-S2** | **S2-S1** | **S4-S1** |
| ***Technological Capabilities*** | | | | | | | | | | | | | | |
| R&D intensity | -0,049 | (-7.59) | 3,03 | 2,21 | 2,51 | 2,79 | 2,88 | 0,82 | 0,65 | -20,8 | -112,5 | 28,5 | 126,1 | -41,7 |
| Scientific and technical journal articles | -0,053 | (-3.74) | 3,21 | 0,88 | 1,58 | 2,16 | 2,66 | 1,15 | 0,80 | -30,7 | -297,3 | 96,5 | 72,4 | 19,5 |
| Patent stocks | -0,070 | (-5.12) | 3,82 | 0,49 | 2,56 | 3,21 | 3,89 | 2,49 | 2,39 | -4,0 | 804,4 | 1004,4 | 4035,0 | 89,4 |
| Gross Enrolment Ratio, Primary | -0,029 | (-8.80) | 2,08 | 2,47 | 2,32 | 2,26 | 2,42 | 0,12 | 0,08 | -33,7 | -78,1 | -72,3 | -183,6 | 185,9 |
| Gross Enrolment Ratio, Secondary | -0,026 | (-8.28) | 1,91 | 1,76 | 1,88 | 1,82 | 2,10 | 0,30 | 0,20 | -32,5 | 2277,2 | 16,9 | -34,1 | -115,3 |
| Gross Enrolment Ratio, Tertiary | -0,216 | (-5.43) | 6,83 | 2,16 | 2,66 | 2,66 | 3,09 | 0,88 | 0,36 | -58,9 | -155,7 | -113,8 | 290,0 | -1,7 |
| Public Expenditure on Education. | -0,031 | (-6.67) | 2,19 | 1,82 | 1,76 | 2,10 | 2,32 | 0,35 | 0,29 | -17,6 | -32,5 | -73,1 | 77,4 | -72,1 |
| Mean years of schooling. | -0,021 | (-11,63) | 1,66 | 1,45 | 1,45 | 1,76 | 1,82 | 0,33 | 0,17 | -46,6 | -138,8 | -57,6 | -34,6 | -1,6 |
| Telecommunications revenue | -0,045 | (-8.48) | 2,89 | 2,92 | 3,05 | 2,97 | 2,70 | 0,41 | 0,41 | 0,0 | 40,6 | -5101,4 | -275,6 | 157,1 |
| Mobile and fixed-line subscribers | -0,035 | (-17.14) | 2,39 | 2,32 | 2,42 | 2,42 | 2,42 | 0,80 | 0,23 | -70,8 | -321,9 | -91,7 | 392,9 | 44,9 |
| Internet users per 1000 people | -0,038 | (-9.34) | 2,58 | 2,66 | 2,66 | 2,66 | 2,66 | 1,83 | 0,43 | -76,5 | 73,4 | 572,7 | 2450,5 | 92,2 |
| Electric power consumption. | -0,015 | (-6.78) | 1,27 | 1,03 | 0,88 | 1,31 | 1,51 | 0,90 | 0,79 | -12,6 | 262,0 | 62,5 | 66,2 | 10,4 |
| Paved Roads. | -0,011 | (-2.94) | 0,96 | 0,10 | 0,80 | 0,88 | 1,58 | 0,43 | 0,42 | -2,3 | 12,3 | 540,1 | 24,3 | 6,5 |
| Registered carrier departures worldwide | -0,010 | (-2.75) | 0,91 | 0,88 | 0,95 | 1,31 | 1,10 | 1,38 | 1,19 | -13,6 | 44,5 | 59,7 | 185,3 | 58,4 |
| ***External Spillovers*** | | | | | | | | | | | | | | |
| Embodied technology transfer | -0,130 | (-2.64) | 5,39 | n.s. | n.s. | n.s. | 1,50 | 0,99 | 1,27 | 28,7 | 219,6 | 14,5 | -239,6 | 63,8 |
| Disembodied technology transfer | -0,162 | (-6.22) | 6,01 | 4,94 | 4,94 | 5,17 | 7,03 | 0,81 | 0,41 | -49,8 | -46,2 | 345,4 | -31,7 | -35,7 |
| ***Technological Specialization*** | | | | | | | | | | | | | | |
| R&D industries specialization | -0,127 | (-7.89) | 5,32 | 5,39 | 4,94 | 5,17 | 5,39 | 0,24 | 0,16 | -33,8 | -82,4 | 45,6 | -451,5 | -1003,9 |
| Pervasive technologies specialization | -0,118 | (-7.18) | 5,13 | 4,94 | 5,39 | 5,59 | 5,17 | 0,25 | 0,19 | -26,4 | 315,1 | 71,1 | -105,1 | 166,3 |
| Dynamic tech. Opport. specialization | -0,114 | (-6.18) | 5,02 | 4,43 | 4,94 | 4,69 | 5,59 | 0,24 | 0,18 | -27,8 | 305,2 | -40,6 | -330,9 | -127,4 |
| Dynamic specialization | -0,269 | (-13.85) | 7,50 | 7,51 | 7,15 | 7,28 | 7,62 | 0,28 | 0,18 | -37,1 | -128,3 | -59,3 | -447,1 | -70,7 |
| Technological diversification | -0,179 | (-16.43) | 6,28 | 4,94 | 5,97 | 6,30 | 6,46 | 0,06 | 0,02 | -67,5 | 80,2 | -62,8 | -87,7 | -224,2 |
| ***Stability of S&T policies*** | | | | | | | | | | | | | | |
| Stability of the science policy | -0,301 | (-3.77) | 7,85 | n.s. | n.s. | n.s. | n.s. | 3,29 | 1,30 | -60,6 | -219,8 | -65,9 | -16,9 | -50,6 |
| Stability of technology policy | -0,157 | (-2.84) | 5,91 | n.s. | n.s. | n.s. | n.s. | 2,42 | 4,45 | 83,8 | 196,8 | -20699,5 | -4138,1 | 101,1 |

(a): Coefficient of variation in final and initial periods; (b): Rate of change (%); (λ) Speed of convergence: $\lambda = \left(-\frac{1}{T}\right)[ln(1-\beta.T)]$, *T=29* years; S4 (Stage 4), S3 (Stage 3), S2 (Stage 2) and S1 (Stage 1) refer to the groups of countries at stages of development reported in Table 1; n.s.: not significant parameters of β in the quantile regression.

Source: Own elaboration

*Cluster convergence* measures the distance between the mean-value of each variable for each group between the initial (1980) and the final (2008) periods (Castellaci, 2011). The results point out that the lower the stage of development, the higher the number of variables that report divergence in terms of technological capabilities. It is especially relevant the increasing and strong divergence of Patent stocks. To a lesser degree, the indicators for Communication infrastructures show also divergence, except for Telecommunications revenue where the comparison between Stages 2-3 and 1-2 shows convergence.

All the indicators of technological specialization converge between countries at Stages 1 and 2, what is probably related to changes registered in the patterns of technological specialization in countries at Stage 1. The distances between groups at Stages 2 and 3 also present convergence, but only in technologies with dynamic technological opportunity and in the enlargement of the bases of knowledge (diversification). The convergence between Stages 3 and 4 only happened in patterns of specialization relative to R&D intensive industries and dynamic technological opportunity for the whole period. There was a clear divergence in pervasive technologies and in dynamic specialization.

The indicator Stability of science policy shows convergence for all the comparison between groups, but the speed of convergence decreases at lower stages of development. The speed of convergence of the stability of technology policies increases at lower stages of development.

The comparison between stages at the extremes (4-1) shows that, in terms of technological capabilities, the distances decreased for the indicators related to the qualification of labor force and R&D intensity, but increased in communications and electric infrastructures. Also, the asymmetries in disembodied technologies transfer fell, which is compatible with the recent trends observed in the geography of R&D internationalization towards developing countries. Nevertheless, there was divergence in the indicator of embodied technology transfer. All the specialization patterns presented convergence except for pervasive technologies, which is a pattern of specialization more compatible with earlier stages of technological advance.

Finally, there was convergence in the role of science policies although, as expected, divergence in the role of technology policies implemented by state-owned-companies.

## 4. The contribution of technological drivers to catching up at stages of development

The empirical model uses the Arellano-Bond (1991) difference GMM estimator, which handles the main econometric issues in the estimation of Equation 7. The empirical model tests four specifications, one for each specialisation variable. Each specification takes alternatively Patents Stocks and R&D expenditures to avoid the correlation between both explanatory variables. Sargan Test, AR(1), AR(2) and Levin_Lin Chu were performed, confirming the validity of the model specification and the no-existence of autocorrelation.

Table 4 presents the results of the equation (6). In all equations, the lagged growth of the dependent variable ($\Delta GPD_{pc}$) is positive and significant at 1% level, which is an evidence that there was catching up linked to advanced technologies in a technology gap context. The growth of the per-capita investment ($\Delta k$) presents the same result for all the specifications.

**Table 4. Empirical model results**

| | EQ(1) | EQ(2) | EQ(3) | EQ(4) | EQ(5) | EQ(6) | EQ(7) | EQ(8) |
|---|---|---|---|---|---|---|---|---|
| *ΔGDP pc* | 0.8078 | 0.8011 | 0.8037 | 0.8022 | 0.8149 | 0.8052 | 0.8953 | 0.8684 |
| | (35.12)*** | (32.94)*** | (33.07)*** | (31.11)*** | (35.39)*** | (33.91)*** | (26.76)*** | (23.51)*** |
| *Δk* | 0.1860 | 0.2117 | 0.1791 | 0.1966 | 0.1832 | 0.1791 | 0.2377 | 0.2473 |
| | (7.16)*** | (8.24)*** | (7.14)*** | (7.70)*** | (7.12)*** | (6.98)*** | (7.73)*** | (8.15)*** |
| **Technological Capabilities** | | | | | | | | |
| *RD* | | 0.0358 | | 0.0204 | | 0.0531 | | 0.0352 |
| | | (2.14)** | | (1.48)* | | (2.73)*** | | (1.74)* |
| *SAR* | 0.0593 | 0.06771 | 0.0594 | 0.0630 | 0.0549 | 0.0798 | 0.0376 | 0.680 |
| | (5.03)*** | (4.89)*** | (4.95)*** | (4.63)*** | (4.73)*** | (5.34)*** | (2.41)** | (3.26)*** |
| *PSK* | 0.0122 | | 0.0106 | | 0.0055 | | 0.0034 | |
| | (1.84)* | | (1.68)* | | (0.87) | | (0.92) | |
| *HK2* | 0.0483 | 0.0616 | 0.0281 | 0.0355 | 0.0467 | 0.0732 | 0.0841 | 0.0737 |
| | (1.42) | (1.75)* | (0.80) | (0.98) | (1.37) | (2.07)** | (1.86)* | (1.70)* |
| *HK3* | 0.0454 | 0.0356 | 0.0481 | 0.0431 | 0.0406 | 0.0138 | 0.0645 | 0.0462 |
| | (2.80)*** | (2.91)*** | (3.03)*** | (2.68)*** | (2.84)*** | (0.67) | (3.20)*** | (1.98)** |
| *TI 1* | 0.0694 | 0.0537 | 0.0572 | 0.0511 | 0.0829 | 0.0491 | 0.1655 | 0.1214 |
| | (2.13)** | (1.50) | (1.64)* | (1.37) | (2.48)** | (1.39) | (3.85)*** | (2.80)*** |
| *TI 2* | 0.0480 | 0.0447 | 0.0613 | 0.0568 | 0.0465 | 0.0432 | 0.0303 | 0.0277 |
| | (2.68)*** | (2.43)** | (3.08)*** | (2.76)*** | (2.57)** | (2.4)** | (1.02) | (0.94) |
| *TI 3* | -0.0121 | -0.0063 | -0.0031 | -0.0098 | -0.0137 | -0.0069 | -0.1622 | -0.0093 |
| | (-1.95)* | (-0.94) | (-2.27)** | (-1.51) | (-2.20)** | (-1.06) | (-2.24)** | (-1.25) |
| **External Spillovers** | | | | | | | | |
| TM | 0.0360 | 0.0251 | 0.0365 | 0.0272 | 0.0318 | 0.0331 | 0.0152 | 0.0190 |
| | (4.49)*** | (5.57)*** | (4.51)*** | (5.97)*** | (3.98)*** | (6.64)*** | (1.43) | (3.05)*** |
| TRANSFER | 0.0737 | 0.0939 | 0.0824 | 0.1194 | 0.1120 | 0.1084 | 0.0538 | 0.0492 |
| | (1.69)* | (2.43)** | (2.03)** | (3.45)*** | (2.81)*** | (3.17)*** | (0.97) | (1.14) |
| **Technological Specialization** | | | | | | | | |
| SST1-RD | 0.1216 | 0.1752 | | | | | | |
| | (1.94)* | (2.31)** | | | | | | |
| SST3-Pervasive | | | -0.1242 | -0.1325 | | | | |
| | | | (-2.33)** | (-2.93)*** | | | | |
| SST2-OTD | | | | | 0.1112 | 0.1877 | | |
| | | | | | (1.83)* | (3.01)*** | | |
| SDYN | | | | | | | 0.0621 | 0.0525 |
| | | | | | | | (1.03) | (0.91) |
| SSMTH | 0.3313 | 0.5406 | 0.3572 | 0.4777 | 0.2521 | 0.5494 | 0.0771 | -0.0020 |
| | (1.10) | (1.63)* | (1.15) | (1.44) | (0.84) | (1.72)* | (0.17) | (-0.00) |
| **Stability of S&T policies** | | | | | | | | |
| TECHSTAB | 0.0507 | 0.0474 | 0.0524 | 0.051026 | 0.0538 | 0.0484 | 0.0299 | 0.0299 |
| | (6.46)*** | (6.09)*** | (6.42)*** | (6.20)*** | (6.15)*** | (5.61)*** | (2.79)*** | (2.92)*** |
| SCSTAB | -0.0012 | -0.0028 | -0.00031 | -0.0021 | -0.0001 | -0.0027 | 0.0538 | -0.0059 |
| | (-0.45) | (-0.97) | (-0.12) | (-0.75) | (-0.06) | (-0.98) | (0.97) | (-1.52) |
| *Sargan test* | 68.50 | 74.91 | 76.99 | 79.02 | 65.09 | 69.7 | 66.99 | 77.47 |
| *AR (1) test* | -2.84 | -1.91 | -2.30 | -1.89 | -2.25 | -2.59 | -2.37 | -1.41 |
| *AR (2) test* | -2.20 | -1.42 | -1.09 | -1.05 | -2.05 | -2.05 | -1.98 | -1.32 |

Significance *** at 1% level; **at 5% level; * at 10% level.

Note: estimations with R&D do not includes South Korea. Source: Own elaboration

Most the indicators relative to *Technological Capabilities* are significant as growth drivers. The R&D intensity is more significant in the specification without patent stocks variable and with the pervasive specialization. The SAR variable (scientific articles) is significant in all the specifications. The growth of patent stocks (PSK) is positive and significant [EQ(1) and EQ(3)] although losses its significance when specialization variables (SST2 and SDYN) are introduced. As expected, the qualification of labour force measured by higher education (HK3) has a positive and significant impact on growth in most of the specifications, while enrolment in secondary education (HK2) is only significant at 5% level in EQ(6). Finally, among the indicators relative to telecommunication infrastructures, the mobile and fixed-line subscribers indicator presents the highest significant impact.

The two indicators for *External Spillovers* are both significant and report the expected sign. Imports of machinery and transport goods (TM) are significant in all the specifications, which supports the hypotheses that embodied technologies in capital goods are relevant to economic growth through technological diffusion and catching up. The indicator for non-embodied technology transfer (TRANSFER) is also significant in most specifications.

The dynamic specialization (SDYN), even with a correct sign, is not significant. The specialization in pervasive technologies (SST3), although significant, presents a negative sign. This result is not expected theoretically. In line with most of the empirical studies, specialization in technologies relative to R&D intensive industries (SST1) shows a low or no significance. Finally, specialization in technologies with dynamic technological opportunity (SST2) becomes the specialization variable with a major significant impact on economic growth.

The stability of technology policies conducted by companies controlled by government (TECHSTAB) is strongly significant (at 1% level) for all the specifications. However, the stability of science policy is not significant in any specification, which is far from expected by theory. A reason for that is that the contribution of the science system is not well captured by patent activity. The patenting activity by the government depends on the institutional conception about what is public and what should be. These different visions reflect on the science and technology policy and in the rules to explore intellectual property rights by universities and public research centres. Therefore, patent deposits by public agents cannot apparently be associated with growth, even being an important factor of capacitation. The positive effect on growth of the national scientific capacitation is already captured by the SAR variable [scientific articles], which is very significant with positive effects on growth.

Using the estimated coefficients of the technological drivers in the econometric model, we obtain the contribution of each driver to the differential of growth (catch up) ($gq_{ij}$) as follows:

$$gq_{ij} = \hat{\beta}_i \widetilde{d_{ij}} * 100 \tag{9}$$

Where, $\hat{\beta}_i$ represents the estimated coefficients for the driver *i* in the empirical model and $\widetilde{d_{ij}}$, the distance between the growth average of the driver *i* in country *j* and the growth average of the countries placed in the next upper stage of development. As all drivers have positive signs, a negative value of $gq_{ij}$ means that the technological driver for a country grew bellow the mean of the upper stage between periods.

We combine two indicators to observe patterns of performance in the run. The first one is the *relative* distance between the GDP per capita of each country in the first year of the observation and the average per capita GDP of the countries located at the following upper stage. The second indicator is the relative distance between the growth of per capita GDP by country and the average growth of per capita GDP at the following upper stage. The combination of both indicators produces two patterns of performance. The pattern of *Divergence* take the countries with negative distances in the initial GDP per capita and in the growth of GDP per capita (negative divergence), as well as countries with positive distances in both indicators (positive divergence). A second pattern, named *catching-up*, takes two different situations. First, countries with negative distances in their initial per capita GDP, but with positive distances in the per capita GDP growth (*forging ahead*). Second, countries with initially positive distances in initial per capita GDP but with negative distances in the growth of per capita GDP (*falling behind*). Countries that made a *positive divergence* or a *forging ahead* were *Winners* in the period, and countries that made a *negative divergence* or a *falling behind* were *Losers*.

Table 5 shows the $gq_{ij}$ values by pattern of growth performance. First pattern is divergence. For countries in Stages 1 and 2, the main drivers of negative divergence are associated with a lower performance in terms of efforts of capacitation in accumulated knowledge, that is, in scientific publications (SAR), R&D efforts (RD) and patenting activity (P). Apart from these drivers, there is no clear observable pattern about what other drivers with poor performance caused the divergence in this group of countries. However, a clearer pattern appears for the group of positive divergence (Singapore, Australia, Norway and United States). It is the better performance in efforts of intangible capacitation (SAR, RD and P) with the stability of technology policies and a certain specialization in dynamic technologies what increased the distances of these countries from the rest.

In relation to the pattern of catching up, the effort in knowledge capacitation (SAR, RD and P), being RD more important and dynamic in countries at the Stage 1, is the main driver that induce a forging ahead pattern. SAR and P take greater importance in countries placed at Stages 2 and 3. The specialization in dynamic technologies (SOTD) and the enrolment in tertiary education (HK3) are other drivers that show a regularity across countries (independently of the stage) to guide the forging ahead process. The telecommunication infrastructures (TI2) and imports of machines and equipment (TM) show a greater role in stages 1 and 2, while the transfer of foreign technology (T) only showed a more relevant role in upper stages (3 and 4) with South Korea and Spain from stage 2. Finally, the stability of technology policy is a driver that displayed a positive and important role in countries at Stage 2.

Table 6 synthesizes the previous results for all countries by calculating the probability of being a Winner under the condition of performing a growth of the driver above the average of the upper stage, as well as the probability to be a Loser under the condition of performing a growth of the driver below the average of the upper stage. Considering [0.7-1] the benchmark for the conditioned probability to be significant, the main observations for the performance of the Winners are the following. At Stage 1, the key-drivers to be a winner focused in technological capabilities, like R&D (RD), qualification (HK3), telecommunication infrastructures (TI2), imports of embodied technology (TM) and specialization in technologies with high opportunities (SOTD). At Stage 2, all the drivers are significant, except the disembodied technology transfer (T_W) and the stability of Science and Technology policy (TECHSTAB). At Stage 3, with a conditioned probability equal to 1, the main drivers associated to win are the capacitation in science (SAR), to perform R&D (RD), the advantages in accumulated and protected knowledge (P), the qualification of labor force (HK3) and the specialization in dynamic technologies (SOTD). There is no clear pattern in Stage 4, probably due to the low number of countries, but it is visible that Science and Technology policy becomes more relevant to win in upper stages.

Alternatively, and using the same values, the main observations for the performance of the losers are as follows. At Stage 1, a low capacitation effort in knowledge assets (SAR, RD and P) and unstable or absent Science and Technology policy (TECHSTAB) elevate the probability to be a looser. At Stage 2, the loss of positions in the run is associated with low scientific production (SAR). At Stage 3, insufficient efforts in telecommunication infrastructures (TI2), in transfer of disembodied technologies by transnational R&D and the absence of a science and technology policy elevate the probability of being a looser in the run. Finally, the loss of leader positions at Stage 4 is mainly associated with a worse performance in terms of patenting activity.

**Table 5. Differential of growth induced by technology driver ($gq_{ij}$). Divergence.**

**Divergence**

| Stage | Country | $Q_{1980}$ | $g_Q$ | $gq_{SAR}$ | $gq_{RD}$ | $gq_P$ | $gq_{HK3}$ | $gq_{TI2}$ | $gq_{TM}$ | $gq_T$ | $gq_{SRD}$ | $gq_{SOTD}$ | $gq_{TECHSTAB}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Negative Divergence* | | | | | | | | | | | | | |
| 1 | Argentina | -30,6 | -5,91 | -1,59 | -0,44 | -0,95 | -0,31 | 0,28 | 0,72 | -0,71 | 67,03 | -0,01 | -2,37 |
| | Brazil | -43,2 | -8,01 | -0,85 | -0,28 | -0,97 | 3,40 | 0,61 | -0,12 | 3,83 | 0,64 | 0,13 | -2,80 |
| | Bulgari | -57,2 | -0,38 | -2,82 | -0,66 | -1,38 | -1,41 | -0,18 | 1,77 | 3,84 | -0,44 | 0,64 | 2,37 |
| | Mexico | -16,4 | -7,99 | -0,87 | 1,02 | -0,87 | 0,26 | 0,57 | 0,22 | 0,57 | -5,83 | -0,21 | -12,62 |
| | Romania | -42,5 | -5,18 | -1,14 | -0,87 | -0,95 | 1,50 | 0,29 | 1,62 | -1,14 | -10,47 | 1,85 | 6,92 |
| | South Africa | -50,8 | -7,57 | -2,84 | -0,31 | -1,27 | -0,53 | 0,24 | -1,10 | -0,75 | 0,14 | -0,02 | 7,42 |
| 2 | Greece | -24,2 | -0,57 | 1,42 | 0,33 | -0,13 | 2,07 | 0,40 | -0,03 | 4,84 | 5,51 | -0,11 | 2,75 |
| | Hungary | -50,1 | -2,07 | -0,28 | -0,39 | -0,34 | 2,46 | 2,14 | 0,81 | -0,67 | 7,82 | 0,16 | 2,75 |
| | Israel | -32,7 | -1,56 | -0,84 | 0,71 | 0,27 | -0,30 | 1,37 | -0,18 | -2,50 | 10,61 | 0,03 | -2,40 |
| | New Zealand | -23,7 | -1,36 | -0,45 | -0,08 | -0,03 | -0,07 | -0,21 | -0,25 | 1,86 | 5,22 | 0,06 | 2,12 |
| | Russia | -62,1 | -0,45 | -2,20 | -0,31 | 6,66 | -0,61 | 2,21 | 2,73 | -0,29 | 1,38 | -0,64 | 2,01 |
| 3 | Italy | -7,7 | -1,60 | 0,97 | 0,15 | 0,84 | 1,13 | 0,48 | -0,03 | -0,63 | 0,28 | 0,15 | -3,02 |
| | Japan | -11,5 | -0,16 | 0,44 | 0,20 | 0,87 | 0,54 | -0,26 | 0,71 | -0,35 | -2,08 | -0,06 | -3,69 |
| *Positive Divergence* | | | | | | | | | | | | | |
| 1 | *Singapore+* | 25,5 | 7,85 | 4,92 | 0,98 | -0,30 | -0,47 | -0,77 | 0,12 | 0,01 | -5,67 | 0,30 | -7,93 |
| 3 | *Australia+* | 3,4 | 1,08 | 0,06 | 0,50 | 0,63 | 0,18 | -0,13 | -0,13 | -0,58 | -3,12 | 0,09 | 2,37 |
| 3 | *Norway+* | 23,9 | 2,28 | 0,17 | 0,16 | 0,88 | 0,30 | -0,05 | -0,35 | 0,06 | -1,89 | 0,03 | 7,21 |
| 4 | *USA+* | 17,9 | 0,29 | -0,34 | 0,04 | 0,68 | -0,17 | -0,36 | 0,03 | 0,00 | 0,05 | -0,04 | 4,70 |

**Table 5. Differential of growth induced by technology driver ($gq_{ij}$). Catching up.**

**Catching up**

| Stage | Country | $Q_{1980}$ | $g_Q$ | $gq_{SAR}$ | $gq_{RD}$ | $gq_P$ | $gq_{HK3}$ | $gq_{TI2}$ | $gq_{TM}$ | $gq_T$ | $gq_{SRD}$ | $gq_{SOTD}$ | $gq_{TECHSTAB}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Forging ahead* | | | | | | | | | | | | | |
| | Chile | -59,3 | 6,09 | -1,84 | 0,22 | -0,62 | 0,21 | 1,05 | 0,62 | -0,31 | -2,01 | 0,61 | -9,02 |
| | China | -91,1 | 18,46 | -0,34 | 1,29 | 0,09 | 4,08 | 5,74 | 1,44 | -1,14 | 123,34 | 0,41 | -1,33 |
| STG-1 | India | -91,6 | 5,71 | -2,66 | 0,24 | -0,52 | 0,01 | 2,74 | 0,65 | -1,14 | -1,52 | 0,03 | -7,67 |
| | Malaysia | -65,2 | 5,54 | -1,67 | 1,92 | -0,68 | 0,36 | 0,81 | 0,03 | -1,05 | -2,63 | -0,18 | -6,92 |
| | Thailand | -79,1 | 8,12 | -1,56 | 15,22 | -0,53 | -0,02 | 2,87 | 0,62 | -1,95 | -10,69 | 0,42 | -5,71 |
| | Turkey | -56,7 | 0,04 | 2,88 | 2,37 | -0,42 | 1,66 | 1,21 | 0,42 | -0,90 | -1,86 | 0,01 | -5,71 |
| SG-2 | Korea | -76,9 | 18,34 | 12,78 | - | 1,90 | 0,93 | 1,35 | 0,61 | 0,50 | 5,31 | -0,14 | 2,45 |
| | Poland | -61,7 | 1,88 | -0,13 | -0,64 | 0,01 | 0,19 | 2,06 | 0,92 | -1,09 | 8,03 | 0,42 | 1,05 |
| | Portugal | -50,5 | 1,46 | 4,94 | 0,71 | 0,38 | 0,20 | 1,35 | 0,42 | -0,89 | 4,68 | -0,24 | 26,42 |
| | Spain | -30,4 | 1,82 | 1,68 | 0,31 | 0,34 | -0,13 | 0,70 | 1,13 | 0,21 | 6,28 | 0,34 | 2,13 |
| SG-3 | Finland | -10,9 | 1,03 | 0,48 | 0,73 | 1,52 | 0,20 | -0,23 | -0,11 | 2,04 | -6,43 | 0,01 | -4,83 |
| | Ireland | -30,7 | 10,03 | 0,74 | 0,48 | 1,24 | 0,72 | 0,92 | 0,27 | 0,14 | 12,11 | 0,26 | -1,55 |
| SG4 | United Kingdom | -21,4 | 3,69 | -0,04 | -0,11 | 0,45 | 0,05 | 0,14 | -0,13 | 0,20 | -2,46 | -0,03 | -3,40 |
| *Falling behind* | | | | | | | | | | | | | |
| 1 | Saudi Arab | 389,8 | -9,38 | -3,41 | 0,25 | -0,87 | -0,02 | 1,84 | -1,46 | -0,66 | 2,25 | 3,01 | -2,41 |
| | Austria | 5,8 | -0,24 | 0,58 | 0,54 | 0,64 | -0,17 | 0,13 | 0,05 | -0,73 | -1,12 | 0,18 | -0,47 |
| | Belgium | 1,9 | -0,30 | 0,47 | 0,17 | 0,80 | 0,04 | 0,21 | -0,14 | -0,84 | -2,49 | 0,00 | -0,91 |
| | Canada | 11,3 | -0,85 | -0,25 | 0,29 | 1,01 | -0,77 | -0,53 | -0,43 | -0,40 | -12,44 | 0,10 | -3,71 |
| | Denmark | 0,3 | -0,32 | 0,11 | 0,59 | 0,94 | 1,00 | -0,23 | -0,06 | 0,52 | -3,06 | 0,10 | 0,14 |
| 3 | Iceland | 50,6 | -4,68 | 1,47 | 1,21 | 1,51 | 1,76 | -0,04 | 0,26 | -0,94 | -80,36 | 0,05 | 3,93 |
| | Netherlands | 13,3 | -0,47 | 0,26 | -0,02 | 0,67 | 0,02 | -0,05 | 0,07 | -0,07 | -10,78 | -0,15 | -2,03 |
| | Sweden | 4,7 | -0,83 | 0,06 | 0,31 | 0,56 | 0,67 | -0,50 | -0,22 | 0,34 | -2,60 | -0,11 | -5,99 |
| | Switzerland | 41,6 | -4,70 | 0,17 | 0,16 | 0,44 | 0,19 | -0,22 | -0,39 | 0,16 | 2,39 | 0,00 | 1,16 |
| | France | 1,1 | -2,36 | 0,15 | 0,04 | 0,54 | -0,09 | -0,12 | -0,10 | -0,17 | -0,82 | -0,01 | -3,85 |
| 4 | Germany | 2,4 | -1,62 | 0,22 | 0,04 | 0,55 | 0,21 | 0,35 | -0,21 | -0,19 | 3,23 | 0,08 | 2,54 |

Source: Own elaboration

**Table 6. The relative importance of technological drivers for the run performance.**

Conditioned Probabilities

| | | ***Drivers above the mean of the upper stage and be a winner*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **P[W]** | ***SAR_W*** | ***RD_W*** | ***P_W*** | ***$HK3_{3\_W}$*** | ***TI2_W*** | ***TM_W*** | ***T_W*** | ***SRD_W*** | ***SOTD_W*** | ***TECHSTAB_W*** |
| STAGE 1 | 0,50 | 0,29 | 0,86 | 0,14 | 0,71 | 0,86 | 1,00 | 0,14 | 0,29 | 0,86 | 0,00 |
| STAGE 2 | 0,44 | 0,75 | 0,75 | 1,00 | 0,75 | 1,00 | 1,00 | 0,25 | 1,00 | 0,50 | 0,25 |
| STAGE 3 | 0,29 | 1,00 | 1,00 | 1,00 | 1,00 | 0,25 | 0,25 | 0,50 | 0,25 | 1,00 | 0,50 |
| STAGE 4 | 0,50 | 0,00 | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 | 0,00 | 0,50 |
| | | ***Drivers below the mean of the upper stage and be a looser*** | | | | | | | | | |
| | **P[L]=1-P[W]** | ***SAR_L*** | ***RD_L*** | ***P_L*** | ***$HK3_{3\_L}$*** | ***TI2_L*** | ***TM_L*** | ***T_L*** | ***SRD_L*** | ***SOTD_L*** | ***TECHSTAB_L*** |
| STAGE 1 | 0,50 | 1,00 | 0,71 | 1,00 | 0,57 | 0,14 | 0,43 | 0,57 | 0,43 | 0,43 | 0,86 |
| STAGE 2 | 0,56 | 0,80 | 0,60 | 0,40 | 0,60 | 0,20 | 0,60 | 0,60 | 0,00 | 0,40 | 0,60 |
| STAGE 3 | 0,71 | 0,10 | 0,10 | 0,10 | 0,20 | 0,70 | 0,60 | 0,90 | 0,80 | 0,40 | 0,80 |
| STAGE 4 | 0,50 | 0,00 | 0,00 | 1,00 | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 |

P[W], probability of being a winner; P[L], probability of being a loser (by stage).

Source: Own elaboration

## 5. Conclusions

The analysis of the role of the technology drivers on catching up by stages of development allows us to deal with the heterogeneity of the process of economic growth. Traditional measures of the evolution of technological asymmetries of a heterogeneous set of Leader and Follower countries, like *β-convergence* and *σ-convergence*, revealed that gaps in the technological drivers become lower during a period of 30 years. The quantile estimation of *β-convergence* (*Q-convergence*) still confirmed this trend; the speed of convergence to more similarity is higher when countries with higher rates of growth are included in a percentile distribution. Nevertheless, a different approach that considers the heterogeneity of development across countries associated with different stages of development [*cluster convergence*], show clear evidences of divergence. Specifically, the divergence is most evident in the technological capabilities for each one of its different dimensions: the capabilities to innovate, the communication infrastructures and, to a lesser extent, the qualification of the labor force. Moreover, the lower the stage of development, the higher the speed of divergence.

The role of technological drivers on catching up also seems to be associated with the stage of development. R&D configures a strategic driver and it plays a crucial role at any stage of development. However, the technological efforts to build capacitation in infrastructures and high qualification characterized the dynamism of the drivers at stage 1. The main difference between countries that forwent ahead with respect to those that diverged negatively was the investment in knowledge assets. It is also worth to highlight the role of the stability of technology policy in China. The new winners at this stage (China, India and also Chile, Malaysia, Taiwan or Turkey), combined industrial and technological policies in this direction. Alternatively, increasing gaps in innovative efforts for capacitation seem to be drivers to lose the run, making higher the distances between leaders and delayers.

At Stage 2, the accumulation of technological capabilities and the capacity to maintain specialization in R&D intensive industries are the main technology drivers. Gaps in the growth of the efforts to generate technological capabilities turn out to be a driver of divergence. Once again, technology policy focused to develop and to maintain technological capacitation in key-industries [R&D intensive] induce a production and technological structural change and configure a new set of potential winners. Stage 3 shows the clearest pattern for technological drivers, highly concentrated in the generation of capability in knowledge; scientific (SAR), technological (P), R&D efforts (RD) and the tertiary education (HK3). Stability of technology policy show a more important role at upper stages (3 and 4).

The conclusion of this work has some policy implications. Neoclassical analysis of long-term convergence usually recommends to countries in lowest stages of growth the opening of their markets to let cheaper the access to foreign embodied and disembodied technologies and to invest in human capital. Nevertheless, this paper reinforces the idea that these policies are insufficient to leap frog to upper stages of development. Capacitation in scientific and technological knowledge [which includes superior education] made the difference between the countries that achieved a forging ahead performance and those that stand behind at longer distances. In some cases, the combination of these efforts with stable technology policies conducted by state-owned companies seem to work well, given their importance in countries that registered positive divergence.

At upper stages of development, the aim is to maintain the leadership, which mostly depends on the performance of leadership at microeconomic level. At these stages, the main drivers are concentrated in the building of capabilities in combination with the technological activity lead by state-owned companies.

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**ANNEX: Identifier code for "correct" specializations**

| OST/FISIR CLASSIFICATION | STATIC TECHNOLOGIES | | | DYNAMIC TECHNOLOGIES | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **TECHNOLOGIES** | **R&D Intensive Industries** | **Pervasive Technologies** | **Dynamic Technological Opportunity** | **Between 80-85 and 86-89** | **Between 86-89 and 90-93** | **Between 90-93 and 94-97** | **Between 94-97 and 98-01** | **Between 98-01 and 02-05** | **Between 02-05 and 06-09** |
| Electrical components | X | X | | | | | | | X |
| Audio-visual | X | | X | X | X | X | X | X | |
| Telecommunications | X | | X | X | X | X | X | X | X |
| Information Technologies | X | | X | X | X | X | X | X | X |
| Semiconductors | X | X | X | X | X | X | X | X | X |
| Optics | X | X | | X | X | | | | |
| Analysis, measurement and control technologies | X | X | | | | | X | X | X |
| Medical technologies | X | | X | X | X | X | X | X | X |
| Nuclear engineering | X | | | | | | | | |
| Organic Chemistry | X | | | | | | | | |
| Macromolecular Chemistry | X | | | X | | | | | |
| Basic materials chemistry | X | | | | | | | | |
| Surface technology | X | | | | | | | | |
| Materials, metallurgy | | | | | | | | | |
| Biotechnology | X | | X | X | X | X | X | | |
| Pharmaceuticals and Cosmetics | X | | X | X | X | X | X | X | |
| Food Chemistry | | | X | X | X | | X | X | |
| Chemical engineering | | X | | | | | | | |
| Printing | | | | | X | | | | |
| Textile and paper machines | | X | | X | | | | | |
| Environmental technology | | | X | X | X | | | | X |
| Agricultural and food machines | | | | | | | | | X |
| Machine tools | | X | | | | | | | |
| Engines, pumps, turbines | | X | X | | | | X | X | X |
| Thermal processes and apparatus | | X | | | | | | | X |
| Mechanical elements | | | | | | | | | X |
| Transport | | X | X | X | | X | X | X | X |
| Aerospatiale and armament technologies | X | | | | | | | | |

| | | | |
|---|---|---|---|
| Consumer Goods | X | X | X |
| Civil engineering | | | X |