JOURNAL OF ECONOMIC DEVELOPMENT
Volume 50, Number 3, September 2025

THE EXHAUSTION OF FIXED CAPITAL IN THE TECHNOLOGICAL STRATEGY OF COUNTRIES

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This paper empirically demonstrates the productivity exhaustion entailed by the continuous accumulation of fixed capital in technological advancement, as part of the imitation strategy adopted by countries. It investigates the relationship between fixed capital per employee and the distance to the technological frontier in terms of Total Factor Productivity (TFP), using panel data from 118 countries during the period 1955-2019. The results reveal a diminishing marginal relationship between physical capital and technical progress in developed countries, especially in the top ten largest advanced economies in the world. These findings suggest the existence of a limit on the amount of capital per worker, beyond which no further technical progress would occur, thus indicating the erosion of the imitative strategy in the long term.

Keywords: Total Factor Productivity, Technological Frontier, Fixed Capital, Technical Progress
JEL Classification: O33, E22, O11

1. INTRODUCTION

The study of countries' progress toward the technological frontier has been, and continues to be, one of the most challenging topics in economic literature. Despite the massive technological progress experienced in recent decades, many countries, including the most developed ones, fail to reach the technological frontier. In general terms, the United States remains the country with the highest technological level today, continuing to set the boundary in global techno-economic dynamics. In the business realm, referring to the Nasdaq-100 stock index, which includes the hundred most important technology companies in the world, it is noteworthy that 89 % of them originate from the United States[1]. In fact, nine out of the top ten are also American, including companies like

[1] As of January 2024; https://www.nasdaq.com/market-activity/quotes/nasdaq-ndx-index

Apple, Microsoft, or Alphabet, each with a market capitalization exceeding two trillion dollars, surpassing the Gross Domestic Product (GDP) of over 95 % of countries.

Likewise, when considering aggregate metrics capable of measuring technological advancement, such as Total Factor Productivity (TFP), within the large advanced economies (OECD[2]), the United States also leads in this regard[3]. Looking back, using the TFP of the United States as a reference, Figure 1 illustrates that, although the evolution of large advanced economies has been relatively positive in the long term, the United States manages to currently distance itself from the rest of the countries[4].

The capitalist system, predominant over the past decades in developed countries, has made capital accumulation its main source of economic growth (Mankiw, Romer and Weil, 1992). In turn, it has served to underpin the foundations of modern knowledge-based economies relying on innovation. However, as pointed out by theory (Acemoglu, Aghion and Zilibotti, 2006), this progress based on the accumulation of capital has limitations and is not sufficient to drive long-term technical progress. Therefore, it becomes necessary for countries to adopt technological strategies based on innovation.

From this perspective, this paper examines the technological evolution of developed countries compared to that of the rest of the world. Considering that relatively easy access to physical capital[5], along with its embedded technology, makes it one of the main sources of imitation for countries, the aim of this research is to demonstrate that the accumulation of capital goods alone is not sufficient to reach and maintain the global technological frontier in the long term. To do so, as depicted in Figure 1, TFP is used to assess the distance of countries from the technological frontier and to examine its relationship with the stock of fixed capital per worker. Thus, it is revealed that although the imitative strategy based on capital accumulation has contributed to significant convergence in developed countries, as exemplified by the case of Spain, the technological drive it ultimately provides fades away when distances close to the technological frontier are reached.

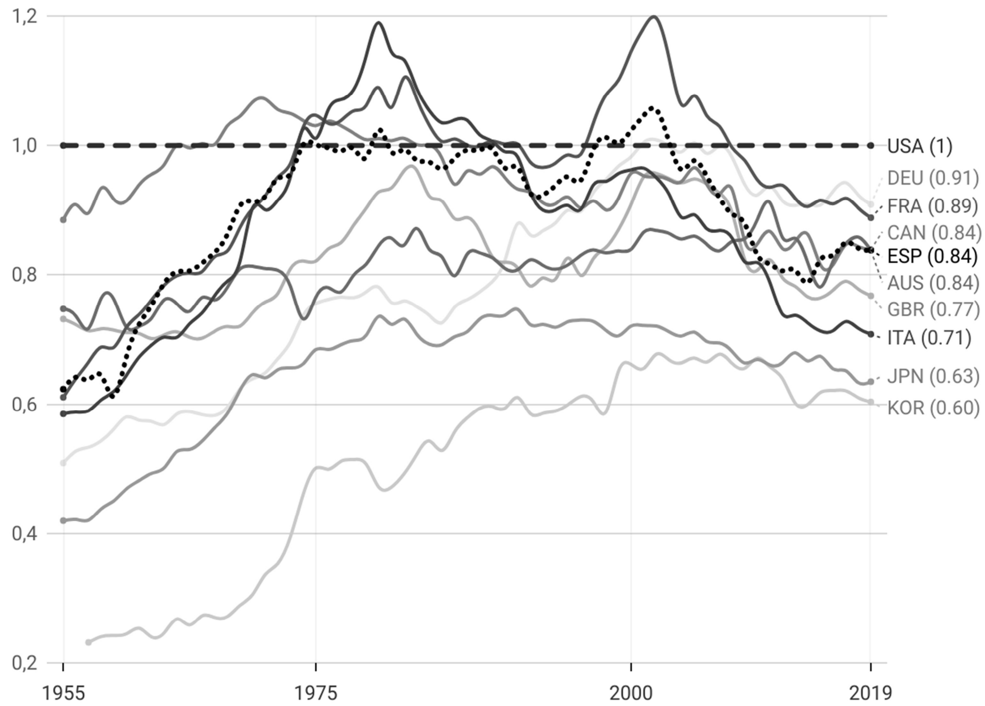
For this purpose, the paper is divided into six sections. Section 2 presents relevant data and reviews the related literature. Section 3 describes the data sample and explains the methodology employed. Section 4 reports the empirical results, and Section 5 provides their analysis. Finally, Section 6 concludes with the main findings of the study.

[2] Organization for Economic Cooperation and Development.

[3] Sources: PWT v.10.0 (https://febpwt.webhosting.rug.nl/Dmn/AggregateXs/PivotShow) and Long Term Productivity (http://www.longtermproductivity.com/download.html)

[4] See Schnabel (2024).

[5] Understood as durable production goods, such as: capital goods, machinery, infrastructure, tangible assets, etc.



Note: United States (USA), Germany (DEU), France (FRA), Canada (CAN), Spain (ESP), Australia (AUS), United Kingdom (GBR), Italy (ITA), Japan (JPN), and South Korea (KOR).
Source: PWT v.10.0.

Figure 1. Total Factor Productivity Gap (TFP GAP), USA = 1

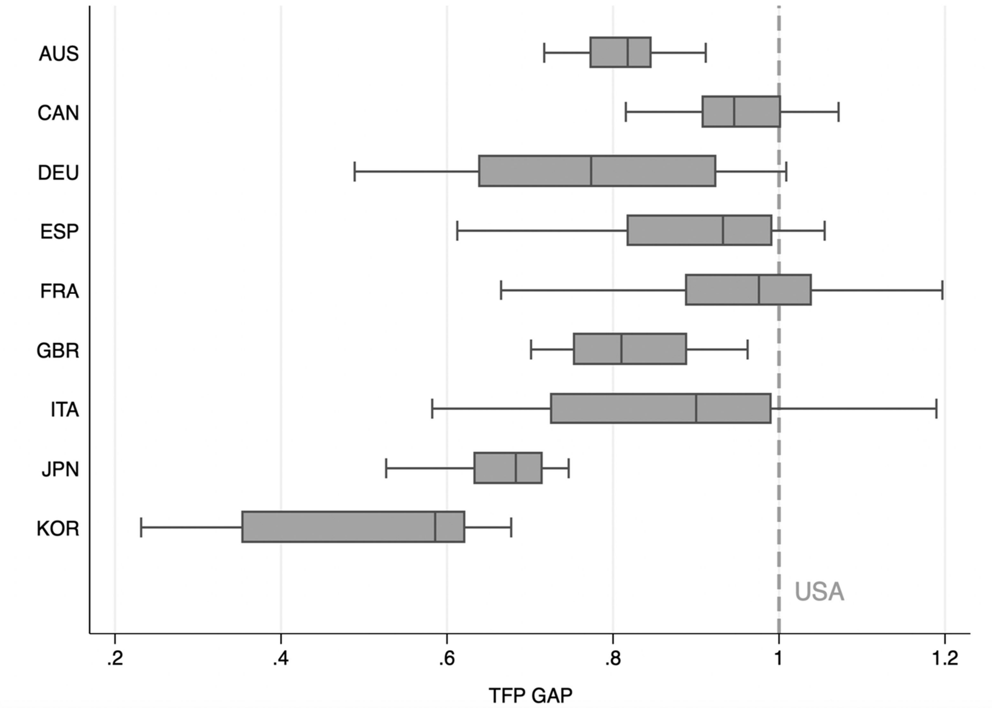
2. SOME RELEVANT DATA AND LITERATURE REVIEW

2.1. Limited Convergence in Total Factor Productivity

The country exhibiting the highest technological level defines what is known as the technological frontier. In the empirical realm of specialized literature, the TFP of the United States is commonly used as a reference to establish this frontier[6]. According to data from the Penn World Table (PWT), the ten largest economies in the OECD have experienced significant fluctuations in their technical progress from 1955 to 2019. Figure 2 depicts the distribution of TFP figures using a box plot, highlighting that only

[6] See, for example, influential works such as: Coe and Helpman (1995); Benhabib and Spiegel (2005); Ha and Howitt (2007).

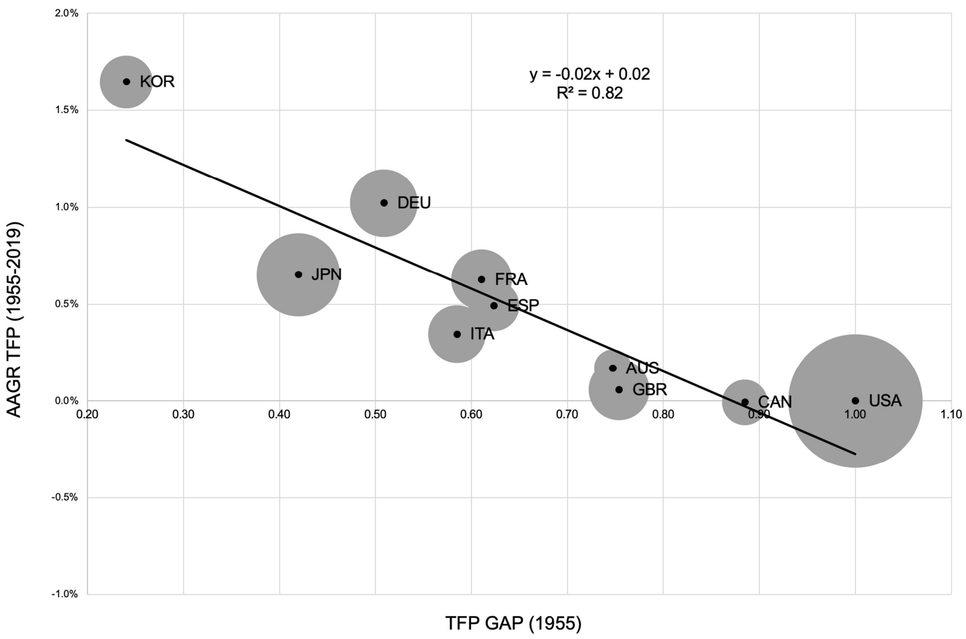
France and, to a lesser extent, Canada, have managed to surpass the level of the United States in 25 % of the annual data. However, the medians of these countries, like the rest, remain distant from this level.



Source: PWT v.10.0.

Figure 2. Distribution Data of Total Factor Productivity Gap (TFP GAP), USA = 1 (1955-2019)

Similarly, when considering the wide dispersion of the data and the predominant trend of the medians in the boxes shifting towards the right, a generalized approach of countries towards the technological frontier in these years can be inferred. This phenomenon appears to be indicative of a convergence process, as statistically evidenced in Figure 3. In this graph, the least squares trend line shows how countries with lower levels of TFP in 1955 exhibit higher average annual growth rates (AAGR) compared to those closer to the level of the United States. However, in this convergence process, three distinct periods can be distinguished where the evolution of the countries followed a similar trend: first, a stage of rapid convergence (1955-1975); second, a phase of consolidation at the frontier (1976-2000); and third, a period of distancing from the frontier (2001-2019). These trends are visualized in Figure 4, which shows the compound annual growth rates (CAGR) of TFP relative to the United States.



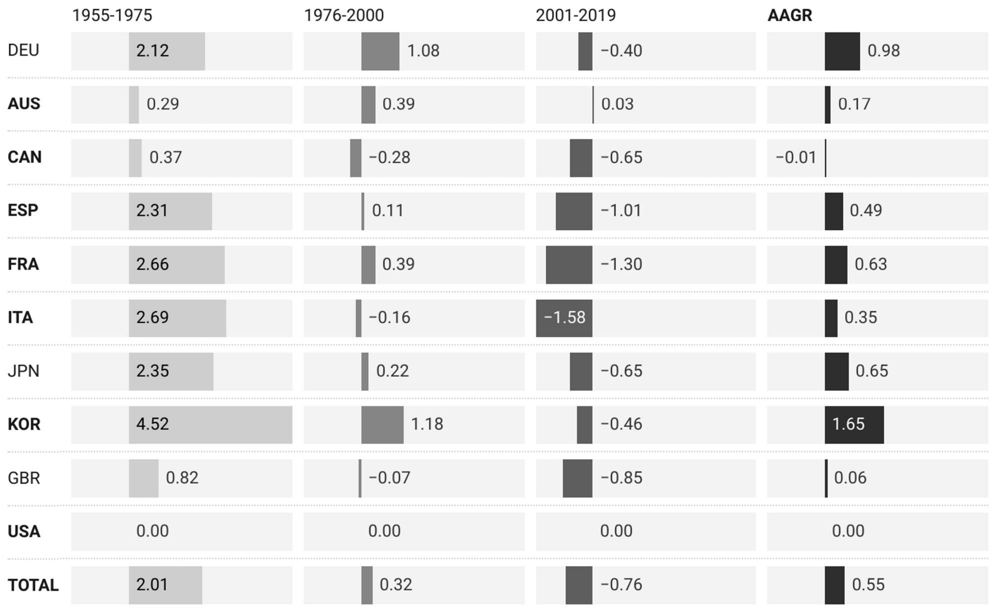
Note: The bubbles represent population size in 2019

Source: PWT v.10.0.

Figure 3. Evolution in the Advancement Towards the Frontier, USA = 1 (1955-2019)

Following this period of widespread convergence towards the frontier, during the subsequent period spanning from 1976 to 2000, most of these countries consolidated their position near the technological frontier. Growth rates stabilized at an average of 0.3 %, with only Germany and South Korea managing to exceed 1 %. By the end of this period, in the year 2000, Germany succeeded in reaching the technological frontier along with Spain and France, while Italy and Canada slightly moved away to around 95 %. The United Kingdom and Australia still lagged in completing the catch-up, positioned at distances between 80 % and 90 %. Meanwhile, the two Asian countries, Japan, and South Korea, ended this period at distances of 72 % and 63 %, respectively.

Therefore, during this period, it can be observed how a large portion of the countries managed to position themselves within the orbit of the technological frontier. This would imply a similar behavior in terms of their technological dedication. However, if we examine the investment in Research and Development (R&D) at the end of this period, in the year 2000, according to World Bank data, only Germany with 2.40 % of investment as a percentage of GDP and France with 2.09 % managed to approach the United States effort, which stood at 2.62 %. Countries like Italy and, especially, Spain failed to exceed 1 % of investment as a percentage of GDP.



Source: PWT v.10.0.

Figure 4. Evolution of the Average Annual Growth Rate (AAGR) towards the Technological Frontier (TFP GAP)

The most recent period, from 2001 to 2019, is characterized by a widespread distancing of countries from the technological frontier. Overall, this distancing occurs at rates exceeding 0.7 % on average annually. Australia is the only exception, managing to slightly approach the frontier with a relative advancement of 0.03 % on average during this period. Even countries that started further behind, such as Japan and South Korea, seem to lose their follower advantage and move away from the frontier at rates of 0.65% and 0.46 % on average annually, respectively. On the other hand, countries that had reached the technological frontier, such as Italy, France, or Spain, experience considerable distancing during this period, with average annual rates of 1.6 %, 1.3 %, and 1 %, respectively. Even Germany fails to maintain its position at the frontier, ending this period at 90 % from the United States level.

Considering the above, a central question arises: is it possible to reach the technological frontier without a strategy based on innovation? According to theory, at considerably distant distances, the imitative strategy proves effective in rapidly approaching the frontier; however, technological catch-up requires innovative effort through an innovation-centered strategy (Acemoglu, Aghion and Zilibotti, 2006). This argument seems to apply to countries like Germany and France, given their levels of investment in R&D comparable to those of the United States. It would also explain the remarkable progress of countries like South Korea and Japan, considering their initial distance from the technological frontier (Howitt, 2000). However, the question arises about the case of countries like Spain and Italy, which show low innovative effort in relation to their location relative to the technological frontier.

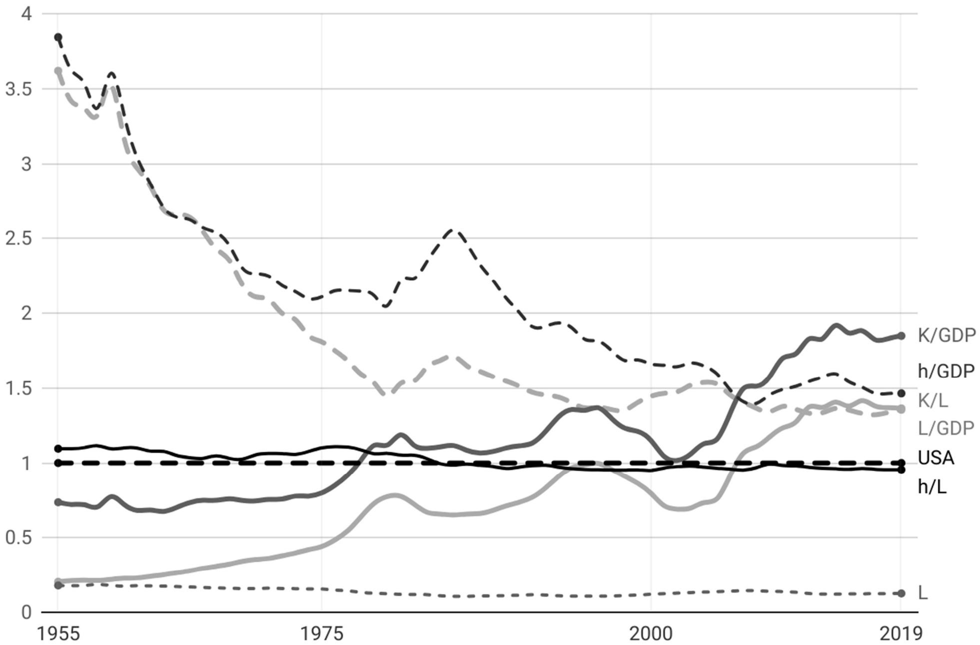
2.2. The Case of Spain

Among the large advanced economies, the case of Spain stands out as one of the most striking. Despite initially being at a considerable distance from the technological frontier in 1955, Spain managed to complete the catch-up process in just two decades and with relatively low investment in R&D. In 1955, Spain's level of TFP represented 62 % of that of the United States, and by 1974, this gap had been completely closed, with a comparative growth rate exceeding 2.3% on average annually during these years. Following this rapid convergence process, Spain maintained a long period of consolidation around the technological frontier, which it even surpassed in some years. In fact, its peak was recorded in 2002 when it reached its highest historical level in TFP, surpassing the United States by more than 5%. However, since then, Spanish TFP has shown a downward trend, reaching its lowest point at the end of the financial crisis in 2014, when it distanced itself to 78% compared to the United States, before recovering and reaching 84% in 2019.

Spain is the best example of a country that, after reaching the level of TFP of the United States, remained at the technological frontier for more than two decades. But how did its main long-term productive factors evolve? When analyzing aggregate factors such as physical capital stock and the labor force, in relation to the technological frontier represented by the United States, significant changes can be observed. This can be seen in Figure 5, which depicts the comparative evolution of Spain's productive factors in different metrics since 1955.

On one hand, examining the accumulation of fixed capital, Spain starts with a level of capital per GDP (K/GDP) equivalent to 78% of the United States in 1955. It is striking that, throughout the entire period, Spain nearly doubles its capital proportion relative to the size of its economy, surpassing the United States ratio by 84% in 2019. In this process, during the initial stage of 1955-1975, Spain maintains a constant capital proportion, which does not exceed 80% of the frontier, coinciding with the rapid convergence in TFP observed.

On the other hand, regarding the evolution of the labor force, it is observed that the ratio of the number of workers (L) in Spain relative to the United States has remained constant and close to 15% throughout the period. Something similar occurs with the number of hours worked per employee (h/L). In 1955, Spain slightly exceeded the working hours of the United States by 11%, and by 2019, Spain was 5% below, maintaining a consistent evolution between these two levels. However, substantial changes in Spain's evolution come with labor effort relative to the size of its economy, whose gap with the frontier has been considerably reduced.

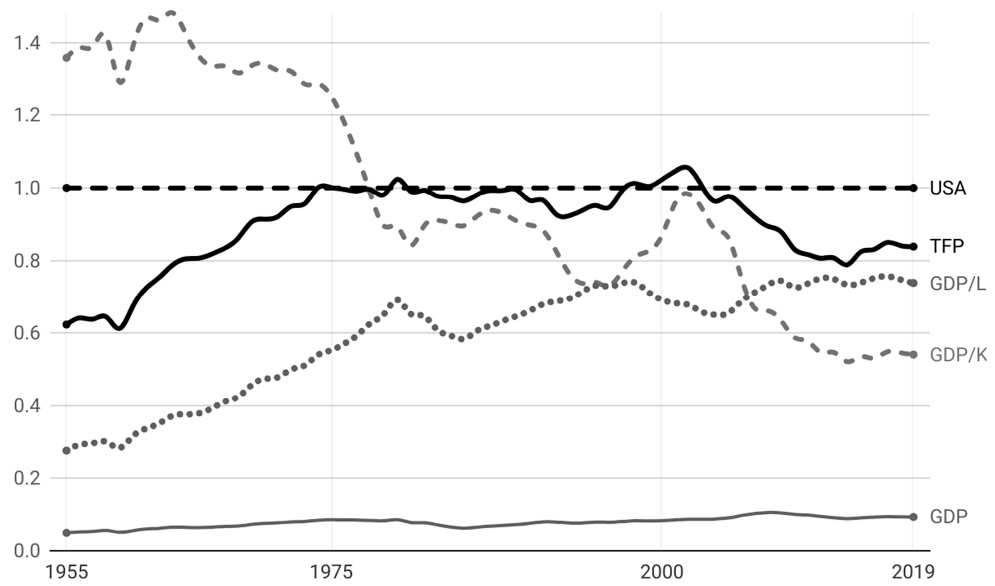


Source: PWT v.10.0.

Figure 5. Production factors of Spain Relative to the United States (1955-2019)

When examining the number of employees used in production (L/GDP), it is observed that Spain employed 3.5 times more workers than the United States in 1955, slightly more when measured in hours worked relative to the size of production (h/GDP). However, this gap was rapidly reduced in the first stage (1955-1975), and this trend even continued until 1980. Currently, the difference in Spain's labor force relative to the size of its economy has not completely closed with respect to the proportion used by the United States. Spain comparatively employs 35% more workers and 46 % more hours of work.

Altogether, this comparison reveals an interesting evolution. In the first stage (1955-1975), when Spain experienced strong convergence towards the technological frontier through TFP, there was a significant increase in fixed capital, and the share of labor input decreased. In the second period (1976-2000), Spain continued to accumulate large amounts of capital, allowing it to remain at the technological frontier and further reduce the proportion of labor input in its production. In the most recent period (2001-2019), Spain did not halt this accumulation of fixed capital, surpassing the levels used by the technological frontier, both in capital per worker and in relation to the size of its economy. This increase no longer translates into a reduction in labor input, which, as mentioned earlier, distances it from the technological frontier in terms of TFP.



Source: PWT v.10.0.

Figure 6. Productivity of Production Factors in Spain Relative to the United States (1955-2019)

The described evolution is clearly manifested in Figure 6, which illustrates the comparative productivities of capital and labor relative to the United States. This graph demonstrates how the comparative total production (GDP) increases in the case of Spain, rising from around 5% in 1955 to nearly 8% in 2019. In 1955, the relative productivity of capital (GDP/K) was much higher than that of labor (GDP/L). However, in the first stage, this strongly reverses towards United States levels, increasing labor productivity and decreasing capital productivity. This change allows for accelerated convergence of TFP towards the technological frontier.

During the second stage, the comparative performance of capital continues to decline and maintains a high correlation with the advancement of TFP, while labor productivity continues its upward trend. In this period (1975-2000), the productivity of Spain's productive factors remains at comparative levels closer to those of the United States, and TFP stays longer at the technological frontier. In 2002, Spain once again increases its capital productivity, bringing it closer to frontier levels and surpassing United States TFP by 5 %. However, following this upturn, capital productivity sharply declines, along with TFP, resulting in a distancing from the technological frontier at present.

In general terms, this comparative analysis reveals that Spain has an excess of fixed capital relative to the size of its economy and its labor force. This comparative overaccumulation, primarily in recent years, reduces the returns of productive capital and distances it from the technological frontier. Additionally, its labor productivity fails to converge to United States levels, and although its long-term trend is upward, it seems to stagnate in the most recent period. However, this latter aspect does not appear to be the main concern, as Spain managed to reach United States TFP without matching its labor productivity ratios. Therefore, the main problem seems to lie in the overaccumulation of physical capital, possibly due to the significant weight of infrastructure-intensive sectors such as tourism (Mas and Robledo, 2010), and the real estate boom since the 2000s (Díaz and Franjo, 2016).

This argument provides a simple and reasonable explanation for understanding Spain's advancements and setbacks towards the technological frontier, as well as those of other countries with similar circumstances and characteristics. However, it could also be argued that the accumulation of physical capital was the key factor in productive efficiency decades ago when countries were focused on rapid industrialization and did not require a high degree of technology. At that time, technology embedded in capital and the imitation of efficient practices provided strong growth, but in the long run, innovation became an indispensable element to continue progressing (Maudos, Pastor and Serrano, 2000).

2.3. Fixed Capital in Technological Progress

Fixed capital plays a fundamental role in economic growth. Numerous models and empirical papers utilize the stock of physical assets to explain the income levels of economies[7]. Furthermore, fixed capital maintains a close relationship with technology. In fact, the line that divides the productive contribution between both factors is quite blurry, and in many cases, it is not easy to individually isolate the accounting participation of physical capital and technological advancement, known as technological

[7] See, for example, Solow (1956), Swan (1956), Romer (1990), and Rebelo (1991). Currently, much of the empirical research on this topic builds upon these methodological models.

progress embodied[8]. This type of progress involves more efficient production methods, better utilization of resources, and the adoption of new technologies through capital goods (Weil, 2005). Technological progress embodied in capital generates automations in activities previously carried out by labor (Acemoglu and Rastrepo, 2019), promotes the diffusion of knowledge (Arrow, 1962), and creates agglomeration effects (Ellison and Glaeser, 1997), ultimately increasing total economic productivity. Therefore, the incorporation of new physical capital not only increases a country's productive capacity but also entails a significant transformation of the structure and production methods of the environment.

In his seminal work, Romer (1986) proposed an explanation for technological progress based on positive technological externalities (knowledge spillovers). According to this theory, knowledge generated within a firm as a result of capital accumulation can benefit other firms and extend to the rest of the economy. In his model, Romer (1990) included these externalities as part of the economy's aggregate capital, arguing that the incorporation of new capital, whether physical or in the form of knowledge, enhances and updates the existing capital. Lucas (1988), on the other hand, presents this idea in terms of capital per capita, primarily emphasizing improvements in human capital. However, both proposals lacked solid empirical support (Sala-i-Martín, 1994). Thus, productive externalities and their intangible contribution to production, through knowledge and accumulated experience in the use of capital goods, are difficult to measure directly[9] but are indirectly reflected in TFP.

In this regard, Molinari and Torres (2018) analyze the technological progress embodied in capital goods in a group of OECD countries during the period of 1980-2010. These authors argue that the technological component of physical capital underlies sustained long-term productivity growth. Precisely, more than 50% of this growth is attributed to investment in these assets[10], surpassing aspects such as information technologies (ICT) or human capital. Another recent study that specifically examines the impact of fixed capital on technological advancement is conducted by Zhang (2020), who investigates the evolution of China's TFP in the long term (1952-2017). This author argues that the growth of TFP in the Asian country is fundamentally due to gross fixed capital investments rather than innovation. Through a Bayesian model, this study reveals that TFP experiences a nonlinear evolution, strongly driven by physical capital initially, but ultimately ends up having a negative impact.

Therefore, while physical capital, along with labor, largely defines an economy's production function, it can also help us explain country's progress toward the technological frontier from an empirical perspective of organizational improvement and

[8] See Phelps (1962) theory of technical progress embodied and the recent paper by Jones and Liu (2022).

[9] There are measures that approximate it, such as the constant-quality deflator of capital goods developed by Gordon (1990).

[10] Hulten (1992) found that approximately 20 % of productivity growth could be attributed to technical change embodied during the period from 1949 to 1983 in the United States.

efficiency. Considering that technology embodied in capital can approximate the imitation strategy, this strategy can generate a strong impetus for the advancement of countries that have not fully exploited all their efficiency mechanisms. However, the contribution of technology embodied in fixed capital should ultimately be exhausted in country's technological strategy. Thus, based on these foundations, the research aims to examine the technical progress generated by the increase in the stock of physical capital and to demonstrate whether its accumulation loses effectiveness in the long term within the technological strategies of countries as economies develop.

3. DATA AND METHODOLOGY

The methodological strategy employed follows the following steps. Firstly, a balanced panel dataset is constructed comprising 118 countries for the period 1955-2019. Subsequently, a non-linear model is introduced to explain, through a regression analysis, the relationship between fixed capital and the distance to the technological frontier across three groups of countries.

3.1. Data

The country data sets are obtained from the database provided by PWT version 10.0 (Feenstra, Inklaar and Timmer, 2015). The total sample used covers 118[11] countries for the period 1955-2019. The study classifies these countries into two main groups: those that do not belong to the OECD and OECD countries. In the latter group of advanced countries, special attention is paid to the behavior of the top ten countries with the highest GDP in 2019. These economies, mentioned in previous sections, are in order of magnitude: United States, Japan, Germany, United Kingdom, France, Italy, Canada, South Korea, Australia, and Spain. This group of countries, with homogeneous and comparable complexities, offers us a more precise insight into the behavior of advanced economies. In all cases, among other parameters, the size of their economies exceeds one trillion dollars (together they represent nearly 50 % of the global economy), their GDP per capita exceeds $40,000 (PPP), and their populations include more than 25 million inhabitants.

3.2. Capital Depletion Model in Technological Progress

To assess the impact of fixed capital accumulation on technological advancement, a non-linear model is employed. The aim is to determine whether the return on capital decreases as countries approach the technological frontier. To do so, as illustrated in

[11] See the countries in Appendix.

equation (1), the distance of countries from the technological frontier is explained by a quadratic function of fixed capital per worker. Thus, if the coefficient β_1 is greater than zero and β_2 is less than zero, the stock of fixed capital exhibits a decreasing U-shaped relationship with the distance to the technological frontier (TFP GAP). Conversely, if β_1 is negative and β_2 is positive, the relationship takes on a U-shape.

$$TFP\ GAP_{(it)} = \beta_o + \beta_1 \log k_{(it)} + \beta_2 \log k^2_{(it)} + \beta_3 X_{(it)} + u_{(it)} + \varepsilon_{(it)}. \quad (1)$$

In Equation (1), $TFP\ GAP$[12] represents the distance to the technological frontier, measured as the ratio of the country's i TFP to that of the United States in period t. $Log\ k$ is the logarithm of the fixed capital stock per worker[13], and $Log\ k^2$ is its square. X is a control variable that adds, depending on data availability, the logarithm of annual working hours per employee (Log hours). u represent the unobserved individual effect, and Ɛ denotes the error for each country in the period.

Table 1. Descriptive Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Countries (118)					
TFP GAP	6.293	0.704	0.263	0.115	1,599
Log k	9.159	4.714	0.657	2.494	6.458
Log hours	3.339	3.292	0.062	3.140	3.482
NO OECD Countries (84)					
TFP GAP	4.286	0.648	0.281	0.115	1.599
Log k	7.126	4.549	0.635	2.494	6.458
Log hours	1.435	3.323	0.050	3.185	3.475
OECD Countries (34)					
TFP GAP	2.007	0.823	0.168	0.231	1.450
Log k	2.033	5.295	0.316	4.344	5.917
Log hours	1.904	3.268	0.059	3.140	3.482
TOP 10 OECD Countries					
TFP GAP	643	0.824	0.179	0.231	1.196
Log k	645	5.317	0.321	4.344	5.890
Log hours	645	3.278	0.064	3.141	3.482

The statistical description of the data used is detailed by subsamples in Table 1. As

12 TFP GAP is already calculated in the PWT v.10.0 database itself, in PPP terms, with the USA set as 1.

13 Capital stock at current PPPs (2017 US$). This stock encompasses structures (residential and non-residential), transportation equipment, computers, communication equipment, software, other machinery, and assets.

can be observed, the maximum distance to the frontier has been limited by removing outliers from the years that exceed the level of the United States by more than 60%, primarily from oil-producing countries. On the other hand, Figure 7 depicts the density of the distributions of the data for capital per worker (Panel A1) and the distance to the technological frontier (Panel A2). In these graphs, it can be clearly seen how OECD economies accumulate a higher stock of capital per worker and exhibit a shorter distance to the technological frontier compared to non-OECD countries.

Before conducting the regressions, the Hausman test is performed to determine if there is a close correlation between the capital data used and the unobserved individual effects of the countries. The test conducted rejects the hypothesis of no correlation, so the measurements are carried out with the fixed effects estimator (FEM). Additionally, given the potential heteroscedasticity of the panel, standard errors are corrected (using the robust option) to avoid biases and inefficiencies in the estimated coefficients. Furthermore, the number of hours worked is included as a control variable related to labor and the intensity of the use of physical capital, given the differences in working time among different countries.

Panel A1. Density Data of Log k Panel A2. Density Data of TFP GAP

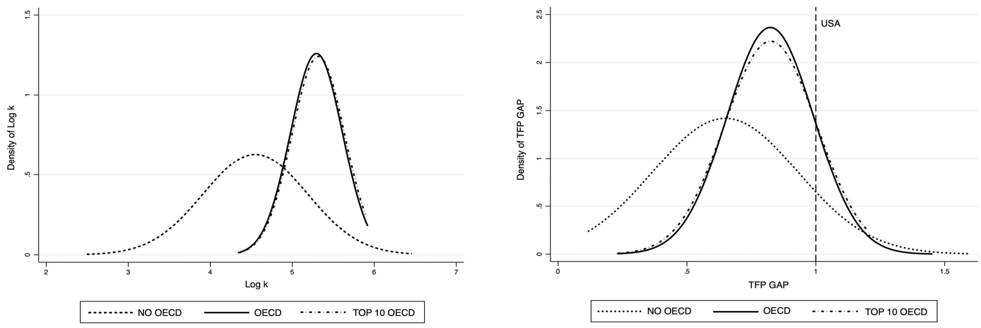


Figure 7. Density Functions of the Country Samples

4. RESULTS

In Table 2, the results obtained for the three groups of countries and the total aggregated are presented. From a general perspective, observing that the coefficients of capital change signs in the quadratic measurements, it is statistically significant that the estimations carried out conform to non-linear relationships in the different cases. In addition to the capital variables, additional measurements with the number of hours worked per employee are included as an explanatory control variable in the amount of capital use, whose statistical relevance also stands out in a general manner.

Regarding the determination coefficients (R^2), it is observed that the variability of the technological progress of countries is largely explained by the accumulation of physical capital per worker, representing up to 61% of the variation in the sample of the TOP 10 OECD countries. However, in these explanations, the relationship between capital and the technological gap evolves differently in the various country samples.

Table 2. Fixed Effect Model (FEM) Regression Results

Var. Dep.	NO OECD		OECD		TOP 10 OECD		TOTAL	
(TFP GAP)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log k	-0.516 **	0.712	1.962 **	3.012 ***	4.321 ***	5.493 ***	-0.989 ***	0.528
	(0.221)	(0.629)	(0.925)	(0.889)	(1.207)	(0.611)	(0.223)	(0.430)
Log k^2	0.065 ***	-0.055	-0.171 *	-0.297 ***	-0.396 ***	-0.535 ***	0.114 ***	-0.041
	(0.024)	(0.061)	(0.088)	(0.082)	(0.116)	(0.059)	(0.023)	(0.044)
Log hours	-	-0.208	-	-0.996	-	-0.955 ***	-	-0.958 ***
		(0.338)		(0.183)		(0.180)		(0.186)
Observations	4,286	1,201	2,007	1,897	643	643	6,293	3,098
Dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Countries	84	30	34	34	10	10	118	64
Adj. R^2	0.420	0.080	0.160	0.290	0.520	0.610	0.180	0.340

Note: Robust standard errors in parentheses and dummy for each country and year. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

The results for the 84 non-OECD countries reveal a growing relationship between accumulated capital and technological gap (1). In other words, a higher stock of physical capital leads to a more significant approach to the technological frontier. However, when including working hours (2), the sample is drastically reduced to only 30 countries, resulting in a regression that lacks statistical relevance and fit. In contrast, in OECD countries, the dynamics are reversed: the quadratic coefficient of fixed capital adopts a negative value (3), indicating a decreasing relationship. In this case, the number of working hours is negative, although it does not reach statistical significance (4). In the specific case of the TOP 10 OECD countries, the decreasing performance of physical capital stock in the technological advancement of these economies is reaffirmed (5). In this scenario, the negative relationship of working hours does become statistically significant (6). Finally, when exploring the total sample composed of the 118 countries (7), an increasing impact of physical capital on technological advancement is evident, attributable to the larger number of non-OECD countries. However, when introducing working hours, there is again a reduction in the sample due to data scarcity, resulting in a higher proportion of OECD countries, and consequently, the relationship becomes decreasing (8).

Therefore, in the long run, the results indicate that, on average, a higher endowment of physical capital per employee tends to bring countries more positively to the technological frontier when the capital stock is relatively low. However, in the case of advanced economies, which have high amounts of capital per employee, its increase no longer represents any additional technological advancement, and its relationship with the technological frontier in the long term is marginally decreasing with a good fit to the model. In other words, the accumulation of physical capital by advanced economies reaches a critical point at which no further progress towards the technological frontier is generated.

To verify the consistency of the obtained results, the estimation is compared with the behavior of imports per worker as an alternative variable for fixed capital. Although imports include foreign acquisitions that are not exclusively limited to physical assets, such as raw materials or services, a large portion of them consists of capital goods. This is evidenced by the strong statistical correlation between physical capital and imports per worker in the analyzed period (see Figure A1, Appendix). Consequently, the regression analysis conducted (see Table A1, Appendix) shows a similar result to that obtained by fixed capital, especially in developed countries. This consistency in the results across different approaches reinforces the reliability and robustness of the findings.

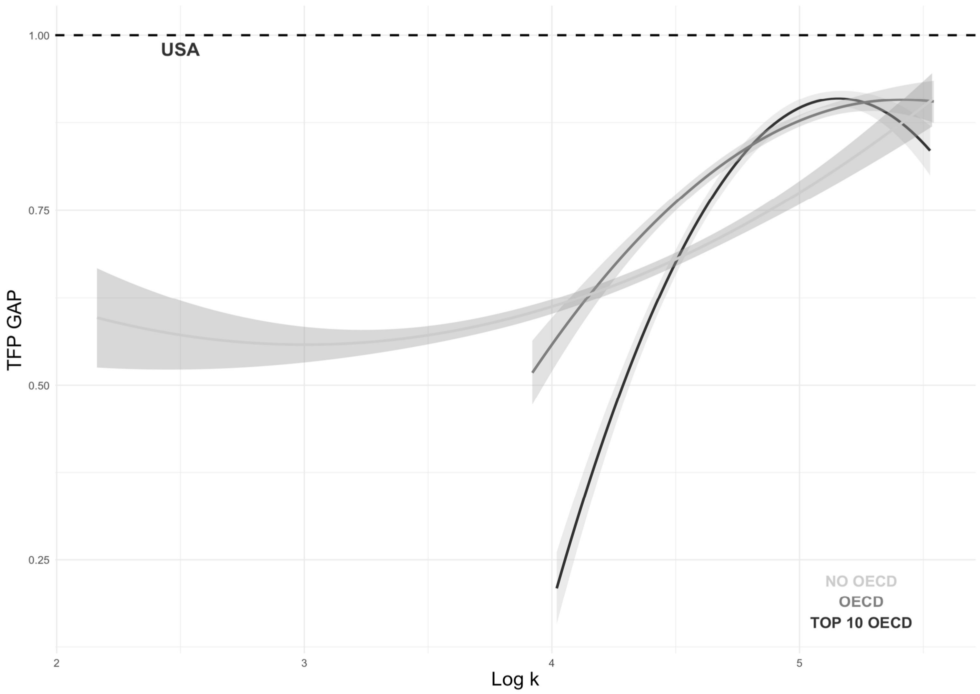
5. DISCUSSION

To analyze the results, the relationships obtained are visually presented. Figure 8 illustrates the evolution of fixed capital per worker in technological advancement for the three groups of countries. This graph makes clear the differences between developed countries that are members of the OECD and those that are not. On one hand, for non-OECD countries, fixed capital maintains a nearly linear and positive relationship with the distance to the technological frontier starting from an intermediate level of capital stock. Beyond this level, these countries progress proportionally as they increase their stock of capital goods.

On the other hand, for OECD countries, a slowdown in technological advancement is observed as countries accumulate large amounts of capital per worker and approach the technological frontier. This trend intensifies in the ten largest economies of the OECD, where a clear diminishing marginal return of capital per worker is evident. This demonstrates that, in these highly developed economies, an increase in fixed capital no longer generates additional technological momentum on its own. This relationship is also confirmed for imports per worker in the TOP 10 OECD countries, serving as a complementary robustness check (see Figure A2, Appendix).

Upon visually examining the evolution over the three periods mentioned above (Figure 9), it can be observed that from 1955 to 1975 (Panel B1), fixed capital maintains a linear and positive relationship with the distance to the technological frontier in all three groups of countries. This relationship is more intense in advanced economies, where the trend shows a relatively steeper slope. During this phase, developed countries with higher stock of fixed capital per worker would manage to position themselves close to the technological frontier.

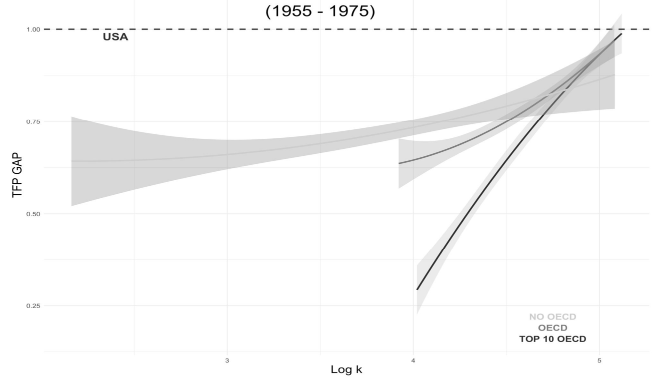
During the following period (Panel B2, 1976-2000), the impact of physical capital on technological advancement in non-OECD countries would accelerate. However, in this phase, a slight deceleration in the progression of developed countries that accumulate a larger amount of capital per worker begins to be perceived. This hint of diminishing returns on capital becomes clear in the most recent period (Panel B3, 2001-2019), especially in the TOP 10 OECD economies. During these latter years, an average negative performance in technological progression based on accumulated capital is observed. In other words, countries with a higher capital stock tend to move away from the technological frontier in the most recent period.



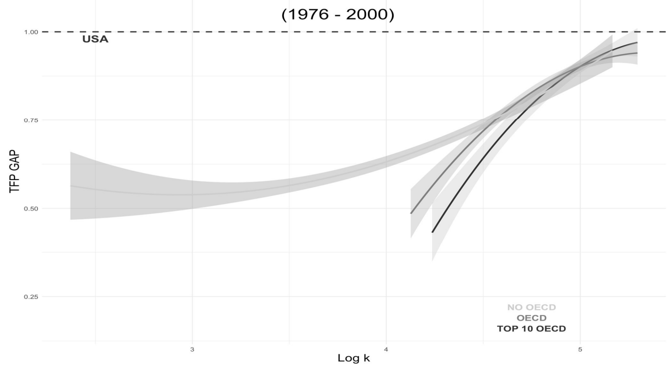
Note: The gray area surrounding the regression lines represents a 95 % confidence interval. The United States (USA) defines the technological frontier with the black dashed line located at unity.

Figure 8. Distance to the Technological Frontier and Fixed Capital Per Worker

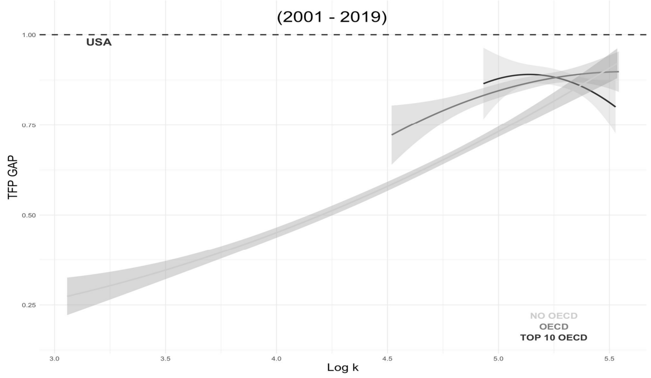
Panel B1. TFP GAP - Log k (1955-1975) (1976-2000)



Panel B2. TFP GAP - Log k



Panel B3. TFP GAP - Log k (2001-2019)



Note: The gray area surrounding the regression lines represents a 95 % confidence interval. The United States (USA) defines the technological frontier with the black dashed line located at unity.

Figure 9. Distance to the Technological Frontier and Fixed Capital Per Worker by Periods.

This exhaustion is also reflected in the rest of the OECD economies, where the technological performance associated with fixed capital decreases compared to the previous period. However, in non-OECD economies, it is observed how this period is the one that generates the greatest impact on their capital stock in advancing towards the technological frontier, reaching a level of performance like what developed economies achieved in the first period from 1955 to 1975. This suggests that physical capital is a key element both in the industrialization of economies and in the reallocation of resources towards the most productive sectors. Likewise, it plays a crucial role in the imitation process through the technology incorporated in capital goods, a phase in which these countries would find themselves.

Empirically, by referring to the estimation of the top ten developed economies (TOP 10 OECD), it can be quantified that the maximum threshold of capital, beyond which technological performance would begin to decline, would be around \$136,000[14] per employee. To put this in context, the United States reached this level before 1950 and Spain in 1978. In 2019, the average capital per worker in the top ten advanced countries was close to \$490,000 per worker. However, for the group of countries outside the OECD, the average capital per employee in 2019 would decrease to \$88,000.

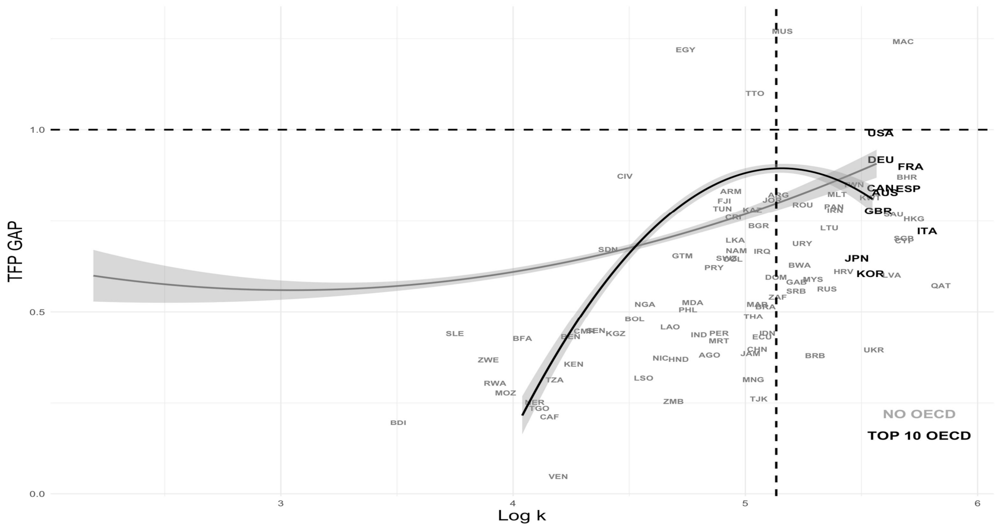
In Figure 10, countries that are still able to establish or continue with a strategy of imitation based on increasing the provision of fixed capital can be identified. In this situation, countries such as India, the Philippines, Tunisia, Paraguay, Peru, Armenia, as well as most African and South American countries would fall. On the other hand, countries like China, Brazil, Thailand, Indonesia, Argentina, or Ecuador are situated in the vicinity of this maximum threshold, suggesting that their technological strategy should be oriented towards innovation. Meanwhile, countries like Uruguay, Romania, Lithuania, Malta, or Malaysia should be immersed in a growth strategy based on innovation, aligning themselves with other developed countries. Therefore, the ingredient of fixed capital in the technological recipe would still be very relevant for many countries, but not for developed economies, whose level of capital attained requires a greater sophistication in their technological strategy, primarily focused on innovation.

According to the results, it is inferred that the accumulation of fixed capital, along with its incorporated technology, plays a fundamental role in imitative activity, generating significant momentum for the TFP of countries with relatively low levels of capital. However, this convergence momentum is not unlimited, and in the long term, the technological frontier moves away from countries that do not innovate. Furthermore, the relative economic lag of countries allows for significant progress in terms of efficiency, as TFP reflects much of this performance. But once a comparable level of efficiency is reached, real differences in technological effort become decisive; the technological frontier moves away again from countries that do not innovate or do not

[14] Maximization of the quadratic function: $f = \beta_1 k - \beta_2 k_2$; $df/dk = f'(k) = \beta_1 - 2\beta_2 k = 0$; $k = \beta_1/2\beta_2$; $k = 5.493/(2 * 0.535) = 5.133\ (log)$; $k = \$136{,}033$.

innovate enough. Therefore, fixed capital would allow catching up in terms of efficiency but not in innovation.

This argument aligns with much of the literature on the subject. For example, Maudos, Pastor and Serrano (2000) highlight the convergence power that comes with the efficiency improvement reflected in the TFP of the countries but also point out that its technological implications do not persist in the long term. Howitt and Mayer (2005) warn about the erosion of technological absorption capacity in the face of continuous advancement through imitation. In this same vein, the model by Acemoglu, Aghion and Zilibotti (2006) graphically illustrates the limitations of insistence on technological advancement through imitation and how countries can thus fall into imitation traps or even become stuck in the so-called middle-income trap (Cherif and Hasanov, 2019).



Note: Fixed capital stock in 2019 is represented for non-OECD countries and the top 10 OECD economies. The gray area surrounding the regression lines represents a 95 % confidence interval. The United States (USA) defines the technological frontier with the horizontal black dashed line located at unity, and the vertical black dashed line represents the critical threshold of $136,000 per worker.

Figure 10. Distance to the Technological Frontier and Fixed Capital (Non-OECD vs TOP 10 OECD)

6. CONCLUSION

This study highlights the diminishing returns associated with the continuous accumulation of physical capital in the technological advancement of advanced economies. Firstly, the long-term technological evolution of countries (1955-2019) was examined through a comparative analysis with the technological frontier defined by the TFP of the United States. This allowed for the observation of partial convergence and three distinct periods in the evolution of the top ten advanced economies: approaching the frontier (1955-1975), consolidation at the frontier (1976-2000), and distancing from the frontier (2001-2019). The case of Spain has served as an illustrative example to analyze the development of the main productive factors in these periods and to demonstrate the relative over-accumulation of fixed capital in different metrics.

For empirically demonstrating the exhaustion of fixed capital as a source of technological progress, a panel dataset of 118 countries covering the period from 1955 to 2019 was constructed. A non-linear model was employed to explain the relationship between the stock of fixed capital and the technological advancement of countries. Through regression analysis, it was shown that the productivity of fixed capital per employee becomes marginally decreasing with the distance to the technological frontier in the long term. On average, when the stock of capital per worker is relatively low, its increase drives a rapid convergence towards the technological frontier. However, once a certain level is reached, which is estimated to be around the threshold of $136,000 per employee, further increases no longer lead to additional technological advancement.

These results empirically demonstrate the exhaustion of the imitation strategy in the technological advancement of countries closer to the technological frontier. The continuous accumulation of fixed capital alone does not enable permanent technical progress. When countries reach a certain level of development, the effectiveness of the technological strategy based on further increasing the stock of physical capital becomes depleted. Therefore, investment in technological imitation loses efficacy in developed countries. In this regard, a threshold in the stock of capital per worker is established, which maximizes the momentum offered by imitation and delimits when it is necessary to abandon this strategy in favor of innovation. This strategic line would generally define which countries are able to orient their strategy towards imitation and which should innovate, thus contributing to the understanding of technological dynamics at different levels of economic development.

APPENDIX

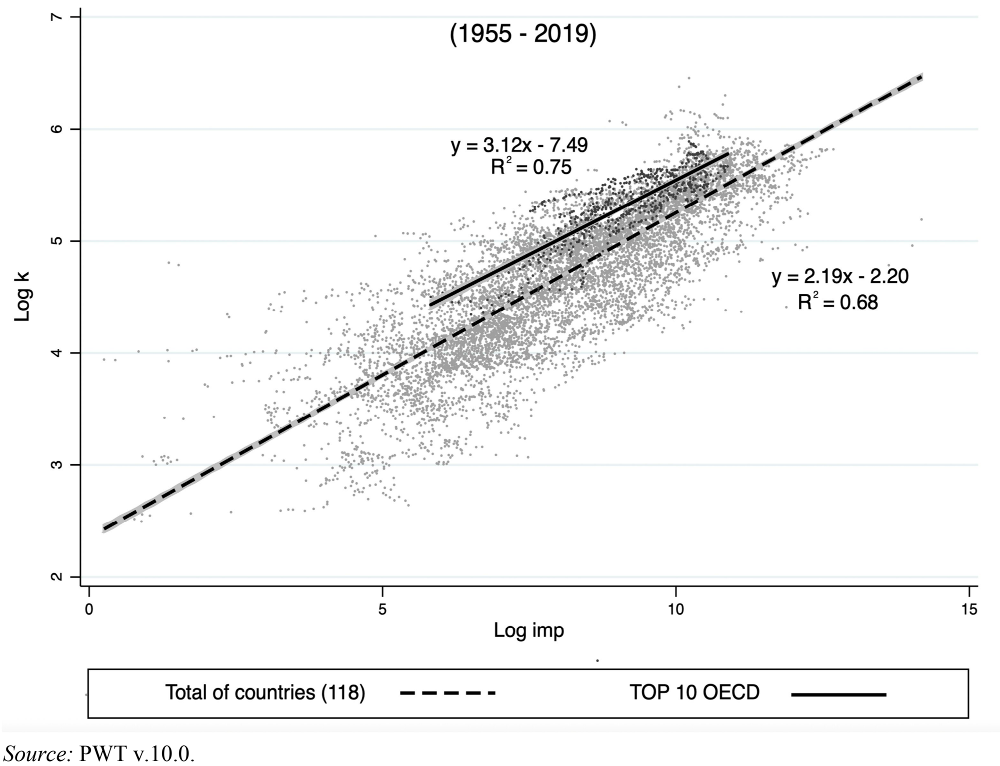
Total number of countries in the sample (118)

OECD Countries (34):

Australia, Austria, Belgium, Canada, Switzerland, Chile, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Iceland, Israel, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, Norway, New Zealand, Poland, Portugal, Slovakia, Slovenia, Sweden, Turkey, and United States of America.

Non-OECD Countries (84):

Angola, Argentina, Armenia, Burundi, Benin, Burkina Faso, Bulgaria, Bahrain, Bolivia, Brazil, Barbados, Botswana, Central African Republic, China, Cote d'Ivoire, Cameroon, Colombia, Costa Rica, Cyprus, Dominican Republic, Ecuador, Egypt, Fiji, Gabon, Guatemala, Hong Kong SAR, Honduras, Croatia, Indonesia, India, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyzstan, Kuwait, Lao People's DR, Sri Lanka, Lesotho, Lithuania, Latvia, Macao SAR, Morocco, Republic of Moldova, Malta, Mongolia, Mozambique, Mauritania, Mauritius, Malaysia, Namibia, Niger, Nigeria, Nicaragua, Panama, Peru, Philippines, Paraguay, Qatar, Romania, Russian Federation, Rwanda, Saudi Arabia, Sudan, Senegal, Singapore, Sierra Leone, Serbia, Eswatini, Togo, Thailand, Tajikistan, Trinidad and Tobago, Tunisia, Taiwan, U.R. of Tanzania, Ukraine, Uruguay, Venezuela, South Africa, Zambia and Zimbabwe.



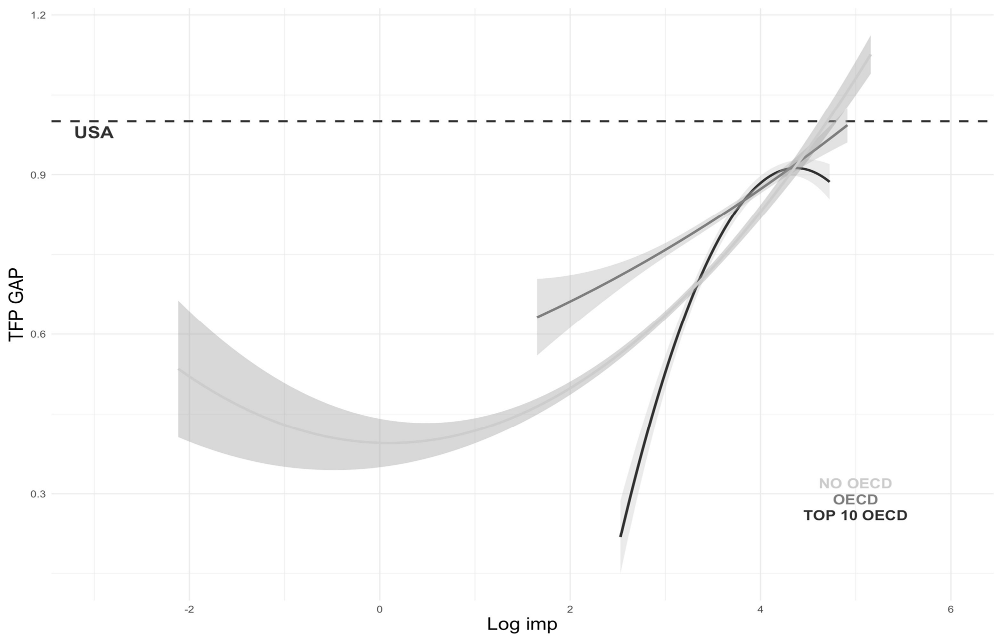
Source: PWT v.10.0.

Figure A1. Correlation Between Imports Per Worker and Physical Capital Per Worker.

Table A1. Robust Checks with Imports Per Worker. FEM Regression Results

Var. Dep.	NO OECD		OECD		TOP 10 OECD		TOTAL	
(TFP GAP)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log imp	-0.006 (0.283)	0.001 (0.005)	0.070 (0.097)	0.243 * (0.135)	0.523 ** (0.181)	0.758 *** (0.137)	-0.047 (0.031)	0.066 (0.050)
Log imp^2	0.000 (0.001)	0.001 (0.003)	-0.001 (0.005)	-0.014 ** (0.006)	-0.025 ** (0.010)	-0.043 *** (0.008)	0.004 * (0.002)	-0.003 (0.003)
Log hours	-	0.277 (0.215)	-	-0.913 *** (0.212)	-	-0.895 *** (0.520)	-	-0.542 *** (0.66)
Obs.	4270	1201	2007	1897	643	643	6277	3098
Dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Countries	84	30	34	34	10	10	118	64
Adj. R^2	0.170	0.170	0.100	0.800	0.390	0.600	0.190	0.260

Note: Robust standard errors in parentheses and dummy for each country and year. *** Significant at the 1 percent level. ** Significant at the 5 percent level.* Significant at the 10 percent level.



Note: The gray area surrounding the regression lines represents a 95 % confidence interval. The United States (USA) defines the technological frontier with the black dashed line located at unity.

Figure A2. Distance to the Technological Frontier and Fixed Imports Per Worker. Robustness Checks with Imports Per Worker.

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Received June 09, 2024, Accepted September 17, 2025.