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Science and mobility: Is physical location relevant?

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Abstract

This article discusses the world distribution of scientists, engineers, and technologists and the movement of these personnel from peripheral countries to central countries. It begins with an analysis of the US as the center of attraction for scientists and technologists, using Latin America as an example. It characterizes mobility and migration flows and examines the migration of Venezuelan scientists and technologists to the US. Finally, it discusses the relevance of intellectual patrimony and physical location in view of the possibilities offered by information and communication technology (ICT).

Keywords: Mobility; Migration; Scientists; Engineers; Information technology; Communications; ICT; Intellectual patrimony; Venezuela

1. Introduction

As science continually develops, it generates change at every level. When discussing the levels of development and the ensuing asymmetries in power relationships among countries, we use the terms "central" and "peripheral." Central countries tend to dominate science and technology worldwide, while peripheral countries are usually subordinate in critical areas such as finance or scientific development. An example is the continuous outflow of highly qualified people from peripheral countries to central countries, attracted by offers of study, competitive salaries, wide-open policies and strategies, and the possibility of becoming part of science or technology workforce. A key focus of this article is the migration of scientists and technologists between Latin America and the US, using the example of Venezuela to illustrate this process, which has been underway for several decades. The unfortunate corollary is that this outflow has created a serious knowledge deficit in the Latin American region.

2. The Triad: a magnet for scientists and engineers

We define the "Triad" as the three regions of greatest development: Western Europe (France, the UK, and Germany), Asia (China, Russia, Japan, and South Korea), and North America (the US and Canada). Together the countries in the Triad are home to approximately 68% of the world's scientists, are located in the

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northern hemisphere, and are the most wealthy. The Triad also includes most of the world's central countries. By contrast, the peripheral countries are not within the Triad and have far fewer of scientists, engineers, and technologists in their professional ranks.

The data highlight the great imbalance between central and peripheral countries. The combined American continents are a case in point: the number of scientists in the region represent 27.3% of the world total but of that total 76.6% can be found in the US, with 8.9% in Canada and Mexico. Central America and the Caribbean have a stock of scientists of 0.5%; and the 11 countries of South America total about 13.9%; among those, Venezuela has 0.5%. Table 1 illustrates the distribution of scientists and engineers in selected countries.

It is generally accepted that skilled scientists, engineers, and technologists are critical to a country's competitiveness and its knowledge society [1], globalization [2,3], and the techno-productive paradigm [4]. However, this issue is more complex than simply arguing that countries are more or less developed according to whether they have or do not have some number of scientists and engineers. In particular, Latin American countries differ in their endowments and capacities, and within the region only a few have the requisite institutional setup that some authors call a national innovation system (NIS) [7,8]. A central element to be considered is the political consensus that must be reached in order to drive the medium- and long-term policies that sustain and promote the construction and optimization of required socio-institutional platforms.

Table 1
World science and engineering population

Continents/selected countries	Year	Total researchers	% of world total
The Americas	2004	1,646,378	27.3
North America	2004	1,408,335	
United States	2001	1,261,226	
Canada	2004	112,624	
Mexico	2004	34,485	
Central America	2004	2395	
Caribbean	2004	5665	
Cuba	2004	5115	
South America	2004	229,978	
Brazil	2004	143,864	
Argentina	2004	37,626	
Asia		2,034,031	36.8
India	1998	117,546	
China	2002	810,537	
Japan	2002	646,572	
Other Asia	2002	459,376	
Africa		60,935	1.1
Europe		1,843,491	33.4
Russia	2002	491,920	
Germany	2002	264,714	
France	2002	177,424	
United Kingdom	1998	157,762	
Ukraine	2000	104,970	
Oceania		76,254	1.4
Australia	1998	62,790	
New Zealand	1997	8264	
Total		5,661,089	100

Source: Refs. [5,6].

Thirty years ago, Derek Price noted that 80–90% of all scientists in history were alive at the time he wrote those words [9]. Growth has been exponential, however, and today there are over 5.7 million scientists and engineers in the world, with more than 90% of them in the Triad. In terms of productivity, the last decade of the 20th century has produced more scientific knowledge than in all of mankind's previous history [10]. Thus, we can grasp the importance of intellectual patrimony, and its repercussions in a country's development and ongoing viability.

This world distribution of highly qualified personnel contrasts sharply with discussions in world conferences, multilateral agencies, and scientific meetings, where it is frequently argued that the aim must be to work for the common good of mankind; that patterns should be established regarding policies and strategies, and programs to help reduce inequities. In reality, the gap between central and peripheral countries continues to grow, and this has much to do with what some authors call innovation-intensive capitalism [11]. Despite this, some societies have managed to organize around solid NIS, which has enabled them to be at the leading edge of the knowledge competition.

One way to look at the knowledge gap between central and peripheral countries is to review the number of scientists and engineers in every country and the relationships between world trade distribution, the generation of new products, and the factors that control them. Educating new generations of scientists and engineers is costly, and poor countries typically do not have strong educational systems nor do they invest adequately in R&D, with the result that scientific and/or technological careers are not promoted. Weakened by continuing poverty, many of these countries are unable to implement the changes that would improve the relationships of education to science, technology, and innovation and the positive impacts their societies would receive in the longer term—simply because their short-term goal is survival.

3. Attracting scientists and engineers: from Latin America to the US

The US has the largest number of scientists in the world, and for decades has promoted policies that attract scientists and engineers who are born and trained in other countries, to work in the United States. At the same time, the US enforces restrictive policies to exclude the entry of poor and unskilled immigrants. What impact does this migratory movement cause in the central and peripheral countries?

The scientific and technological differences between the US and Latin America is enormous, as shown in Table 2.

Although conditions differ from country to country in the region, no country has reversed its handicap of underdevelopment. Countries such as Brazil and Mexico, which in the 1970s were comparable to South Korea in output and R&D investment, a decade later lagged behind [7], and today the distance between them is more than double. These indicators show different trajectories in the development dynamics, which, in the case of the US, have enabled it to grow and consolidate its NIS. With a 13:1 ratio in the number of researchers relative to all of LAC, the labor force has 7.4% researchers per 1000 inhabitants, contrasting with the LAC average of 0.8% [12]. This relates specifically to marked differences in education, science, technology, and innovation, as well as the presence of a solid institutional setup in the US that is much less developed in Latin America. The number of university graduates in a given year is greater in LAC than in the US, but when one looks at their

Table 2
Science and technology comparisons between the US and LAC[a]

	2006	2000		2004	2004		2004		2004
	Total population (million)	GDP US$ (million)		% GERD/ GDP	Science & technology staff		Graduates		No. of publications
		Total	Per capita		Total	Researchers	University	Doctors	SCI
US	300	9,963,000	32,400	2.66	2,330,000	1,261,226	662,995	34,384	363,562
LAC	544	1,944,872	4100	0.53	–	291,241	1,321,333	11,949	36,745

[a]LAC: Latin America and Caribbean. *Sources*: Refs. [5,6].

progress toward higher academic degrees, the number of Ph.D. degrees awarded in the US is 21% versus 1% in LAC; the number of publications is 91% higher than in LAC. This reflects the gap in the knowledge pools of the two regions.

As the 20th century progressed, the US became the most attractive destination for Latin Americans due to multiple possibilities for employment, stable economic development, cultural factors, and other factors that have for decades been powerful attractors. This is apparent in Fig. 1, which illustrates the increasing volume of emigrants from Latin America moved to the US in the last 40 years.

The increasing movement is clear, but the reasons differ depending on immigration policies. Some countries have explicit policies that allow entry of highly qualified immigrants that are in short supply and are of potential intellectual and economic benefit to the recipient country. The events of September 11, 2001, resulted in somewhat fewer entries due to increased security restrictions, which in turn had a somewhat negative effect on science education programs that are traditionally fed by large numbers of foreign students [14].

Several studies [12,13,15–21] reveal that the continual stream of researchers leaving Latin America for the US has hampered the southern Americas' scientific and technological capabilities, weakened its research communities in their role as drivers of economic, social, and cultural change, with the result that it is more difficult to develop scientific leaders. According to 1999 data from the National Science Foundation (NSF), the number of people with science and engineering diplomas living in the US was 12,490,100, of whom 1,559,500 (12.5%) were foreign-born. Further analysis finds that foreigners with Master of Science degrees represent 15% of the total and those with Ph.D. degrees 26% of the total, which means that as their academic level rises, foreign-born immigrants are more attracted to the US. A recent study of the countries of origin of highly qualified foreigners who have settled in the US showed that over 70% were born in peripheral countries [22].

Figs. 2 and 3 show the number and academic level of people working in science and engineering activities.

According to RICyT data [6], in 2007, the total number of researchers in Latin America and the Caribbean was 238,030. According to NSF data [24], 13% of foreigners working in R&D in the US came from Latin America (194,100), most of whom were Mexicans (37,400), Cubans (25,700), Jamaicans (16,600), Colombians (15,800), and Argentinians (12,500). Generating similar data for the number of foreign Ph.D. holders in the US, we find that those from Latin America represent 5.6% of the total (12,000 out of 211,500); for those holding an M.Sc. degree, the numbers are 11% (54,600 out of 504,600). The total number of people from LAC with advanced degrees was 66,600 or 27%. These figures indicate that of the 13 countries in that region that have R&D personnel in the US, more than half (8) live in the US rather than in their own countries. In four of those countries (Brazil 143,864; Argentina 37,626; Mexico 34,485; Chile 20,189) the number of people with Ph.D. degrees who work in R&D activities in their own countries is significantly higher (236,164 against 8,100), that is, only 3.4% of them work in the US. When looking at the figures for Ph.D. holders in these four countries against their population, the ratio changes. Chile has the best ratio (0.12%), followed by Argentina (0.1%), Brazil (0.07%), and Mexico (0.03%). When these values are compared with the international indicator proposed by UNESCO and OCDE—one researcher for every 1000 population—the entire region is far below the agreed minimum standard for requisite numbers of S&T personnel.

These numbers are even more important when one considers that the time needed to train a researcher is between 20 and 25 years, and an investment that may reach US$80,000, depending on the discipline and the

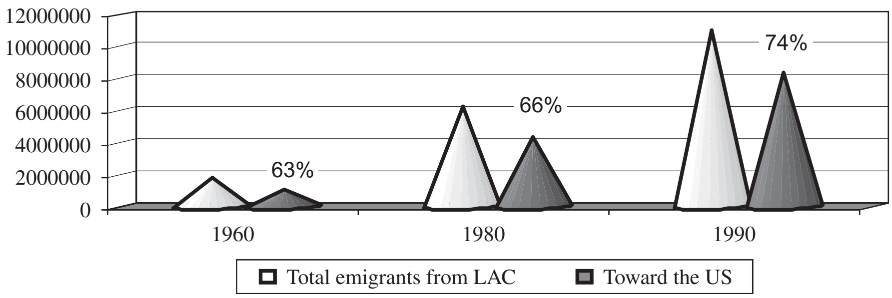

Fig. 1. Emigrants from LAC to the US. *Source*: Ref. [13].

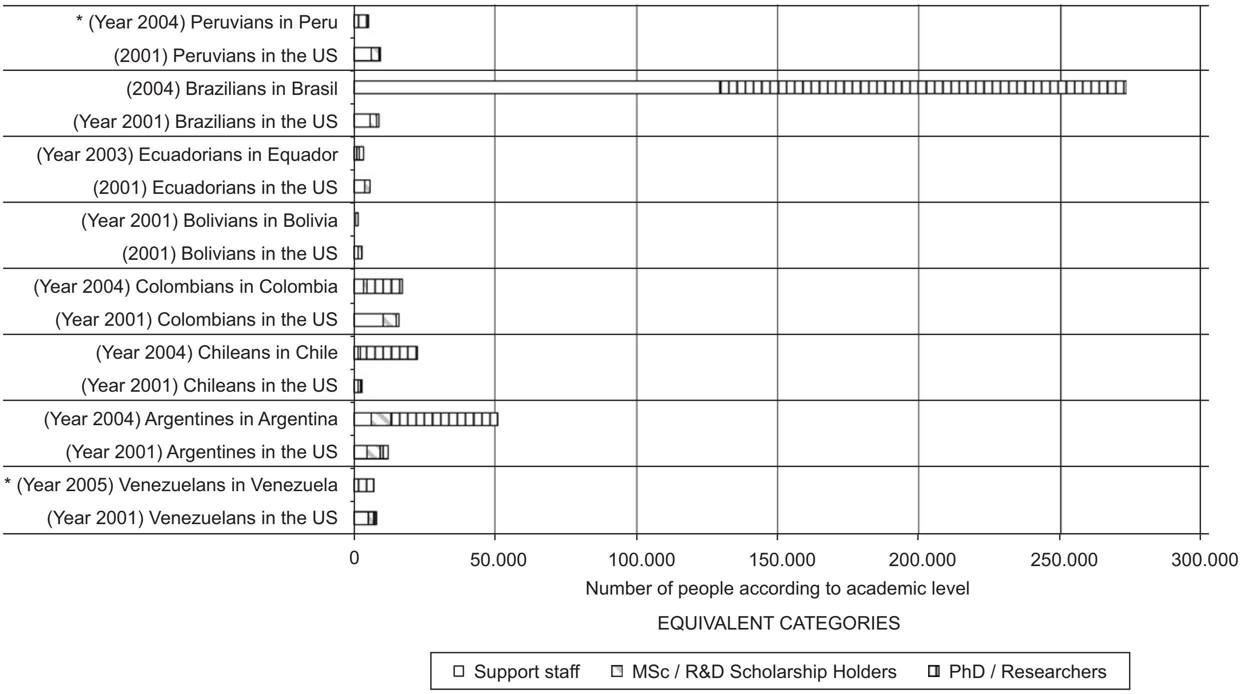

Fig. 2. Comparison of R&D workers in South American countries and the US. *Notes*: (1) Peru and Venezuela give data only for researchers and (2) to make numbers from the two sources comparable, figures corresponding to M.Sc. in the NSF data are equivalent to 'R&D scholarship holder' in RICyT files; Ph.D. figures from the NSF are equivalent to 'Researcher' in RICyT. *Sources*: Refs. [6,23].

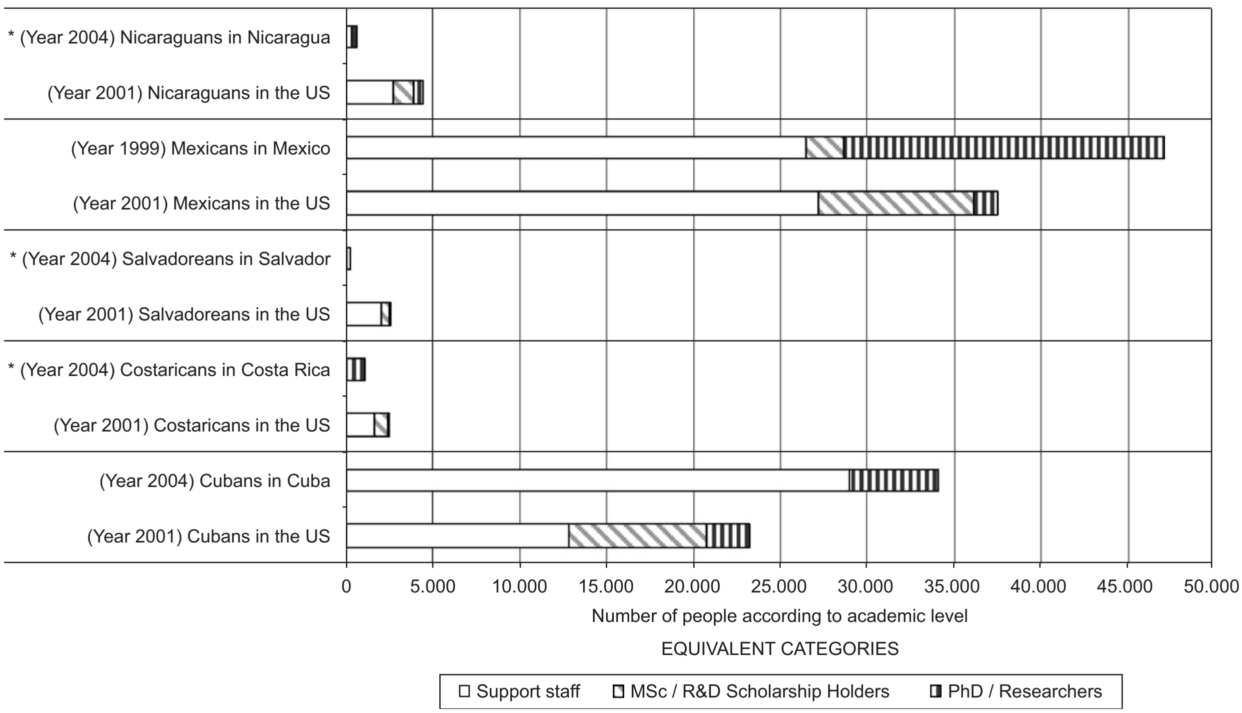

Fig. 3. Comparison of R&D workers in Central American countries and the US. *Notes*: (1) Costa Rica, Nicaragua, and El Salvador give data only for researchers and (2) to make numbers from the two sources comparable, figures corresponding to M.Sc. in the NSF data are equivalent to 'R&D scholarship holder' in RICyT files; Ph.D. figures from the NSF are equivalent to 'Researcher' in RICyT. *Sources*: Ref. [6,23].

country. This means the loss of potential research in certain specialities of keen national interest; the obsolescence of infrastructure and equipment going to waste for lack of use; the failure to attract new generations of researchers because domestic research careers are not viewed as attractive, and salaries that are well below those offered in industrialized countries. The data in Table 2 showed that the deficit of researchers in Latin America is a meager 0.04% of the 1% required, while in the US it is 0.73%.

4. The case of Venezuela

Venezuela is an excellent example of the ongoing loss of intellectual patrimony from a peripheral country. In recent years, Venezuela has suffered continuing emigration of its scientists and engineers to central countries, mainly the US. But this was not always the case.

From the 1940s to the beginning of the 1980s, Venezuela had its own influx of foreigners. A skyrocketing economy due to oil revenues helped to finance accelerated modernization that needed a foreign labor force to reach the targets desired by the country during that period. Immigrants with varying qualifications contributed to Venezuela's development and left a noticeable cultural legacy at every level. Among these were teachers, researchers, engineers, technicians, builders, and farmers. However, since February 1983 a socioeconomic, political, and cultural crisis appeared, which deepened with time, causing many immigrants to return to their countries of origin or to some other destination.

Conditions in Venezuela compared with other countries in the region enabled it to receive groups of immigrants from other countries in more or less defined waves in time. In the 1950s and to a lesser extent in the 1960s, people with a variety of qualifications arrived from southern Europe, mainly Spain, Italy, and Portugal (see Fig. 4). Difficult post-war condition were a key driver propelling those immigrants to move to countries like Venezuela, which offered job possibilities and a sense of peace. The other peak in Fig. 4 took place during the 1970s, mainly due to advantageous work conditions, salaries similar to or higher than in some central countries, and the presence of earlier immigrants who offered a sense of cultural familiarity. Later, the same figure shows that those born in the three European countries began to return to their homeland as conditions in Venezuela began to deteriorate, and improvements began to appear in the European region in general [15].

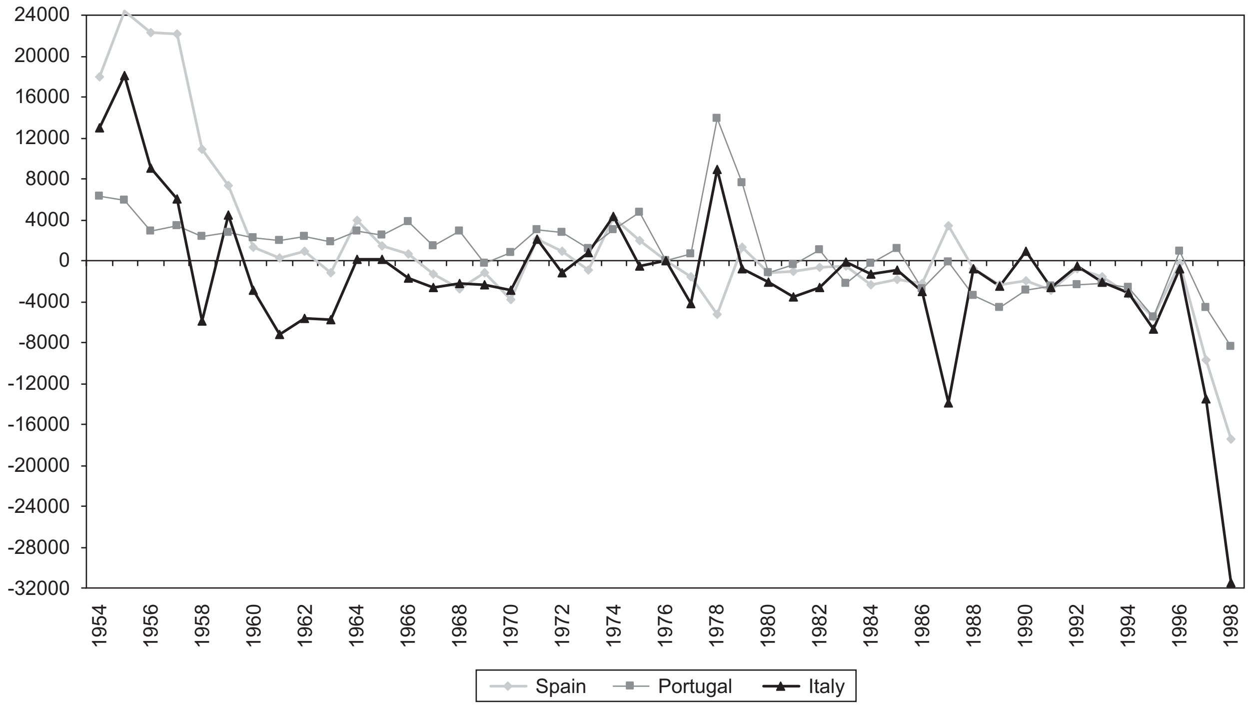

Fig. 4. European emigration to Venezuela (1954–98). *Source*: Ref. [25].

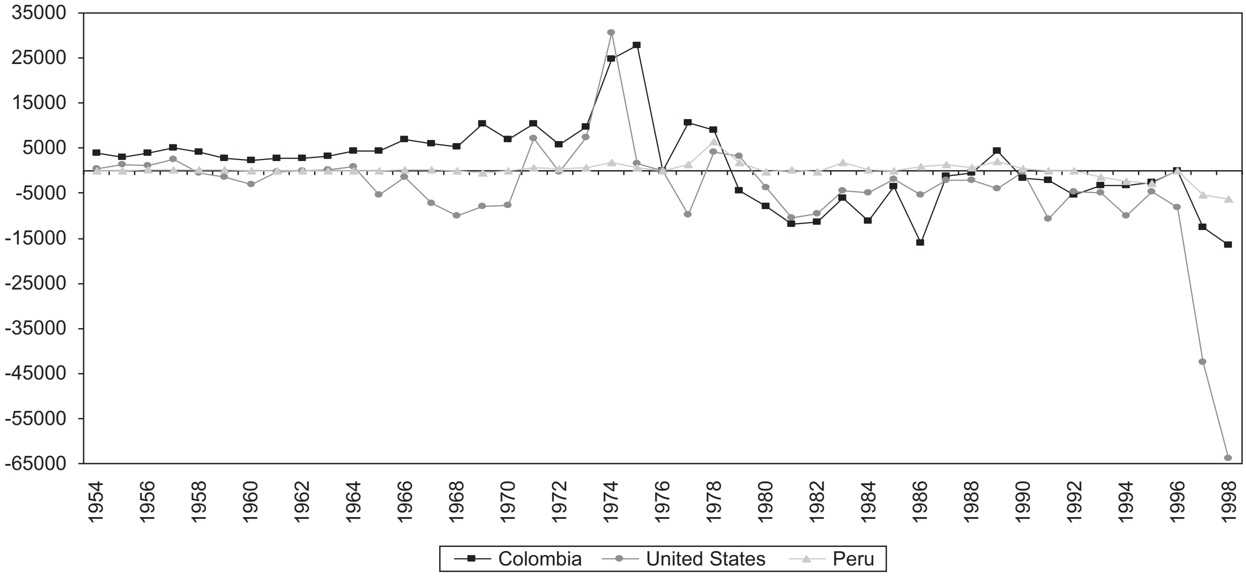

Fig. 5. Migration into Venezuela (1954–98). *Source*: Ref. [25].

Fig. 5 shows the constant entry of Colombians since the 1950s, with a slight increase in the 1960s, and a peak of over 25,000 by the mid-1970s. By that time, Colombia was engaged in domestic problems with guerrillas and drug trafficking, among others. At the same time revenues from domestic goods were declining, salaries declined, and unemployment grew. In comparison, Venezuela offered job opportunities and excellent socioeconomic conditions through the early 1980s, making it attractive for low-income people who crossed the border in search of work.

The immigration of Americans to Venezuela has taken place since the beginning of the 20th century; however, Fig. 5 reflects information since the 1950s. Positive and negative fluctuations can be seen from the 1950s to the mid-1960s, at which time the balance became negative until 1971. Since then it increased by more than 25,000, and then became negative until the present. The immigration of Americans into the country was due to US control of Venezuela's oil industry until it was nationalized in 1976.

Peruvian immigration was different because there was a positive balance of relatively small groups continually coming into Venezuela, except for 1968, 1969 and 1970, and then 1980 and 1982 when there were low negative balances. In the 1990s sustained emigration again became noticeable. In 1981, it was estimated more than 21,000 Peruvians lived in Venezuela, and mose had low qualifications [26].

Migration from the southern regions of South America to Venezuela was significant, especially during the 1970s. Between 1974 and 1981, 43,269 people from Argentina, Chile, and Uruguay entered the country, representing 20.5% of all foreigners. This group had higher qualifications than the other groups coming to Venezuela [27], and many were employed as teachers and researchers in local universities and research institutes [28,29]. Their reasons for migrating to Venezuela were similar to other immigrants, but this group also sought to leave behind dictatorial regimes present in their native countries. Fig. 6 indicates that in the 1950s there was a positive inflow of small groups into the country. By the 1960s, however, the balance had become negative due to economic contractions in Venezuela and protectionist labor measures applied at the time. The 1970s marked the arrival to Venezuela of important contingents from the southern regions, with the 1974–1979 lapse as the apex. The 1980s saw an exit of large groups from the country, with positive and negative flows fluctuating until 1990 when an almost constant exit began.

These Venezuelan inflow and outflow migration patterns are clear indicators of conditions in the country at different times. Two major periods can be seen with an inflection point in 1983. The first was immigration between 1936 and 1982. This is confirmed by the 1981 Census which found that 7.5% of the population was of foreign origin (1,074,629 out of 15,024,000) [30]. The second period was emigration, which began in 1983 and

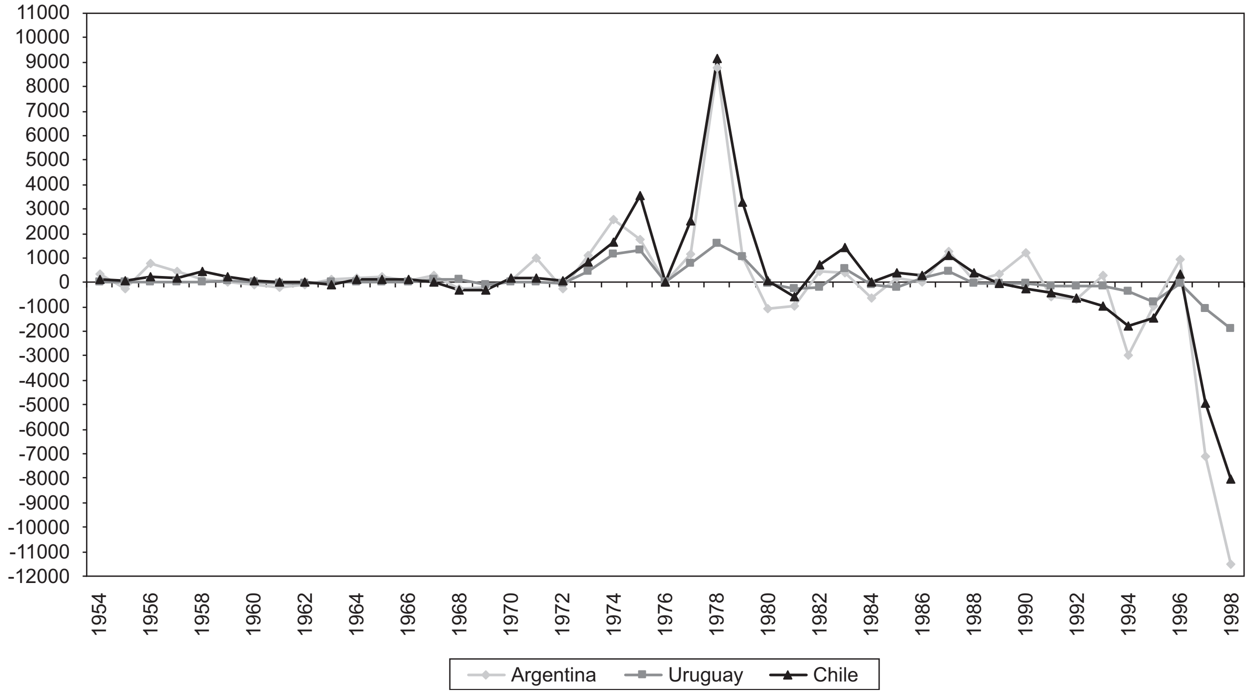

Fig. 6. Migration from South American countries into Venezuela (1954–98). *Source*: Ref. [25].

continues to the present, involving not only the immigrants who had arrived at different times but now including native Venezuelans in the emigration wave—an occurrence not seen since the times of the dictatorial regimes of Gómez (1908–1935) and Pérez Jiménez (1952–1958).

Fig. 7 shows the growing number of Venezuelans who have immigrated to the United States. Between 1970 and 1982, the number of people immigrating was less than 1000 per year, a clear indication that Venezuelans were not interested in emigrating as their country was politically and socially stable, work conditions were favorable, economic incomes high, and most enjoyed a general sense of wellbeing. However, in the so-called ''lost decade'' of the 1980s due to economic crisis, there was a sustained increase in the number of emigrants, reaching 2000 annually into the US. During the 1990s, the curve fluctuated between 2300 and 3400 per year, until 2005 when the number surpassed 10,000 entries (Fig. 8).

Among emigrants from Venezuela who are scientists and engineers, a paradox emerges: trained researchers who do not find adequate employment outside of academia—already a limited number—usually, are successful in finding such positions abroad. According to the data of the Venezuelan System for the Promotion of Researchers (SVPI), in 2005, there were 7164 researchers in Venezuela who were registered in the program. At the same time, there were 8800 Venezuelan professionals in the US working in R&D activities, of whom 2000 had Master's degrees and 800 had doctoral degrees [24]. Of the total settled in the US, more than 50% already have American citizenship and another 3000 have resident visas (over 90%). When looking at the institutions where those scientists work, we found that in Venezuela more than 95% work in universities; 77% of them do so in six academic institutions [32]. By contrast, in the US, the proportion is similar but reversed: 81% of them work in industries or firms, 11% in government laboratories, and only 8% in universities [23].

Since the latter half of the 20th century, Venezuela has been engaged in a sustained effort to rebuild its intellectual patrimony in every field of knowledge. Public and private univrsities, the Venezuelan Institute of Scientific Research (IVIC), the National Fund for Science and Technology (FONACIT), the Gran Mariscal de Ayacucho Foundation (FUNDAYACUCHO), and the Fund for Research in Hydrocarbons and Technical Personnel Training for the Oil industry (FONINVES), have all been major supporters of more than 44,000 people who have undertaken graduate studies (specializations, Masters, Ph.Ds., and post-doctoral degrees) [33]. Many of these native researchers work in the country today, but a significant portion also live abroad.

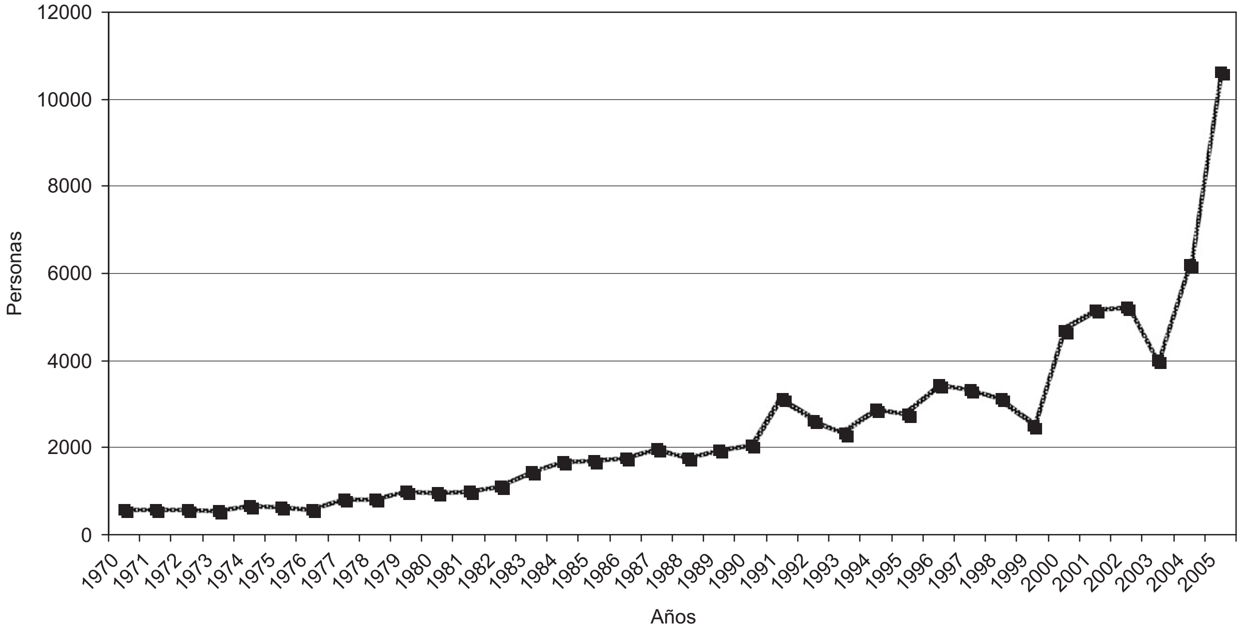

Fig. 7. Venezuelans immigrants to the US. *Source*: Ref. [31].

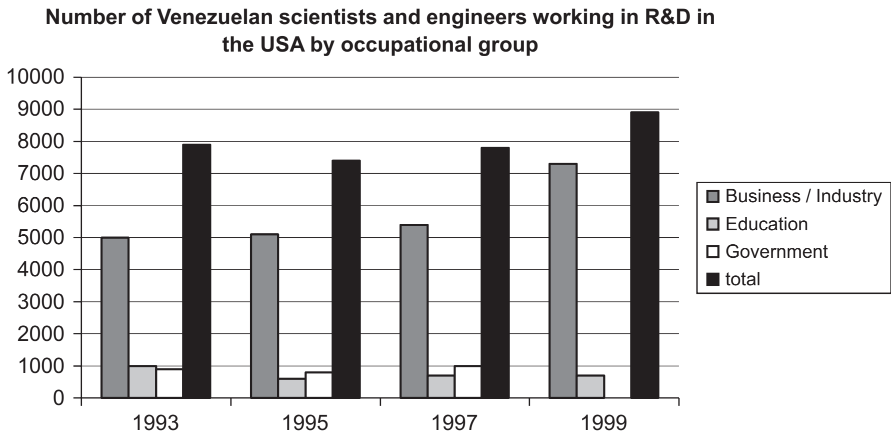

Fig. 8. Venezuelan scientists and engineers engaged in R&D in the US. *Source*: Ref. [24].

Why do the great majority of researchers in Venezuela work in universities? The logical answer is that this is the natural place in a country that has been unable to link the production sector to research. This has a dual explanation. The country's modernization process, underway since the mid-20th century, did not allow many processes to mature. Because scientific and technological issues were not incorporated into the entrepreneurial and industrial concerns, it was impossible to obtain the benefits that might otherwise have been realized. For several reasons, many in this group did not view investing in R&D to be a strategic move. Perhaps the most significant was the exhaustion of the imports substitution process.

Although import substitution was beneficial during its early years when the country's industrial structure was being established, in the long run that strategy became a liability, having a negative effect on domestic production due to the absence of other key measures needed to sustain the process, such as technological learning, the creation of entrepreneurial networks or productive chains to obtain greater profit and yield, and the lack of consistent state policies. The economic bonanza of the 1950s and early 1960s inhibited innovation.

The absence of scientific and technological activity in domestic firms and public industries damaged the country's educational system, which had trained thousands of professionals who were no longer usable locally. This is reflected in the fact that almost 9000 are now working in the United States, most of them for industries and firms.

5. Does it matter where intellectual patrimony is located?

In many cases, scientists are now concentrating on problems linked to global issues and less on solving the problems of peripheral countries. How can these individuals help their own countries? What percentage do help? Under what circumstances? Who benefits from this intellectual patrimony? Do information and communication technologies (ICT) threaten loss or create it? Could they create additional opportunities for peripheral countries? If so, to what extent? These questions are difficult to answer, for the processes are new and complex, and network changes occur along with market interests [21].

When considering these questions, several elements must be considered. One appears often in the literature on migration: there is some interdependence between expelling and receiving countries, a fact that highlights the diminishing separation among the economic, political, and social domains of countries [34]. Another is the new focus on the rights of individuals in a world where national cohesion and a nation's future may be undergoing restructuring.

A key question arises as new forms of networking are developed, giving scientists and engineers the ability to work from any place on the planet. The increased mobility and migration of qualified people (which has in fact been occurring for decades) are the outgrowth of major changes that have occurred in higher education and scientific research capabilities. Other factors also force people to move. The current move to globalization, and the vulnerability of domestic financial markets, affect R&D stability and its potential for expansion [35]. For scientists and engineers, even if there is expansion of high-quality academic research that does not necessarily result in high-quality industrial R&D. In fact, the industrial sector could become a strategic partner for facilitating further change. Thus, it is possible that scientists and engineers may migrate in order to work in their research specialty if they do not find adequate or opportune conditions to develop their intellectual potential or strengthen their íntemational credentials [16].

Another element has to do with international scientific cooperation, which historically has made peripheral countries excessively dependent on foreign sources of knowlege provision. This dependence dries up local initiatives that may be seeking development that is suitable to local conditions [36]. One answer to the lack of dialogue between scientists who migrate and their colleagues who remain behind has to do with issues of confidentiality: many of the emigrant scientists move into firms and industries where confidentiality is required. Another element is that the research conducted in the new location often involves technologies that are not available in peripheral countries.

ICTs have transformed commonly held beliefs and patterns of migration for scientists and engineers, creating new global conditions and lifestyles [37]. ICTs are a natural outcome of continually evolving science and technology, but they must become implanted and assimilated. They encourage expansion of innovation and research networks, enabling local, national, and international players to interact with greater fluidity, creating a virtual workplace that produces and distributes knowledge. But to date, this virtual workplace has not reduced the migration of scientists and engineers from peripheral countries to central countries, and there has been little narrowing of the existing gaps, despite increasing use of the technologies.

When examining the flow of scientists and technologists from peripheral countries to central countries, two complementary elements appear. The first focuses on what emigrating scientists and engineers can do for their countries of origin. For example, if some of their work was done in virtual networks in a central country, the relocated scientists and engineers could help identify solutions to problems or give advice via the web. They could also offer virtual consulting, teach in distance/video conferences, give opportunities to young students from their peripheral country through short stays in their current work location, participate in virtual regional graduate networks, and even pay visits to their country of origin to help with domestic projects, among other possibilities [38].

The second element recognizes the fact that there are already virtual networks in place to help resolve international issues, and many scientists and engineers born in peripheral countries now live in central countries and work on these issues. But they have not yet reduced the gap between centers and peripheries, for several reasons: these emigrating personnel are a relatively recent phenomenon; there is enormous work required to break down complex and anachronistic arrangements, and the peripheral countries exist at different levels of development. However, scientists and engineers living in advanced countries could serve as spokesmen and representatives of their countries of origin, generating relationships that could benefit both sides. Indeed, while interactions are increasing, they are largely dominated by groups and interests within the Triad that have clear aims centered largely on economic gain rather than the need for substantial improvements in living conditions among the world population. Research has found that ICT developments accelerate economic, social, political, and cultural change [39]. However, we recognize that this is a relatively recent process, although one with great potential for direct benefits.

6. Conclusion

Evidence of the concentration of scientists and engineers in the Triad is unequivocal. Countries in the Triad are the wealthiest and most powerful in the world, with education and living standards far above those in peripheral countries. Triad countries are where virtual networks function best—a technologically updated variation of Price's ''invisible colleges'' [9]. Innovation, intensive capitalism is directly linked to maintaining high R&D investment, and this includes a highly qualified labor force. The Triad constantly attracts intellectual resources from peripheral countries, which weakens local conditions.

The realities of the global world are apparent in the disparities between rich and poor countries, between central and peripheral nations, between the 20% and 80% of the world population that resides on one side or the other of the information divide. The Triad has a dominant influence on global markets, and peripheral countries cannot compete without institutional frameworks that allow them to manage needed change in today's world marked by continuous advances in technoscience.

The extraordinary growth of ICTs in recent years has created a new global climate that is beginning to transform the collective mental maps of mankind, but in the process limitations and conflicts have emerged as well. One change that has occurred relates to the emigration of scientists and engineers, mainly from peripheral countries to central countries. Is it possible that this emigration might not mean a net loss to their countries of origin, but instead could utilize virtual networks to take advantage of their knowledge and experience from wherever they may be located?

Venezuela is a clear example that highlights several of the points discussed in this article. Conditions point to a loss of intellectual patrimony, noticeable not only in the migratory outflow but also found in the national effort to train thousands of professionals in scientific and technical fields who have not found adequate employment in the domestic market due to economic and social imbalances. This process has led to a large concentration of researchers in a few national universities, which diminishes opportunities and often leads to emigration in search of better professional advancement. The result is a situation in which huge numbers of the scientific community are now linked to R&D activities in firms and industries in the US instead of contributing to the national wealth so badly needed by their native countries.

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