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Dynamics of R&D Efforts, Patents, Exports and Economic Growth by World Trade Region, 1990-2021

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Abstract

This paper has two objectives. First, to compare the dynamics of R&D/GDP (%), resident patent applications, high-tech exports -VATX- (%), and the innovation and economic growth patterns of countries in North America, the European Union and Asia between 1997 and 2021. Second, to estimate the impact of R&D/GDP and resident and non-resident patent applications on VATX for each selected country through an ARDL model in the period 1997-2016. Results show that countries with more resident patent applications have more VATX. Overall, the effect of the number of resident patent applications and R&D expenditure on VATX depends on the dynamics in each country. Thus, in the United States, Germany, Japan, and China, the effect of the R&D, the number of resident and non- resident patents applied for, on the tendency to VATX is positive, while in the rest of the economies, the results are mixed. Comparing the dynamics of innovation and economic growth between the "old" and "new" members of the European Union, we find evidence of differentiated patterns, with the "old" members' economic growth is particularly linked to the sustainability of innovative activity, supported by continuous R&D efforts, while among the new members some are beginning to build the virtuous circles that will lead them to sustainable economic growth. The differences are also evident among the USMCA countries, where the United States is the leader and Mexico has dispersion and erratic growth rates, showing that economic growth is not significantly related to innovation. In contrast, in the Southeast Asian region, the dynamics of innovation and GDP grow in a sustained and articulated manner over time.
JEL Classification: O30, O31, O32, O57.

Keywords: patents, economic growth, cointegration model, Mexico, NAFTA, European and Asian countries.

Dinámica de los esfuerzos de I+D, Patentes, Exportaciones y Crecimiento Económico por la Región de Comercio Mundial, 1990-2021

Resumen

Este documento tiene dos objetivos. En primer lugar, comparar la dinámica de la I+D/PIB (%), las solicitudes de patentes de residentes, las exportaciones de alta tecnología -VATX- (%), y los patrones de innovación y crecimiento económico de países de América del Norte, la Unión Europea y Asia entre 1997 y 2021. En segundo lugar, estimar el impacto de la I+D/PIB y las solicitudes de patentes de residentes y no residentes en las VATX para cada país seleccionado mediante un modelo ARDL en el periodo 1997-2016. Los resultados muestran que los países con más solicitudes de patentes de residentes tienen más VATX. En general, el efecto del número de solicitudes de patentes residentes y del gasto en I+D sobre las VATX depende de la dinámica de cada país. Así, en Estados Unidos, Alemania, Japón y China, el efecto de las variables I+D, número de patentes residentes solicitadas y tendencia a VATX es positivo, mientras que en el resto de las economías los resultados son mixtos. Comparando la dinámica de la innovación y el crecimiento económico entre los antiguos y los nuevos miembros de la Unión Europea, encontramos evidencias de patrones diferenciados, destacando los antiguos miembros que su crecimiento económico está especialmente ligado a la sostenibilidad de la actividad innovadora, apoyada por los continuos esfuerzos en I+D, mientras que entre los nuevos miembros algunos están empezando a construir los círculos virtuosos que les llevarán a un crecimiento económico sostenible. Las diferencias también son evidentes entre los países del TMEC, donde Estados Unidos es el líder y México presenta tasas dispersas y erráticas de crecimiento e innovación, lo que demuestra que el crecimiento económico no está significativamente relacionado con la innovación. Por el contrario, en la región del Sudeste Asiático, la dinámica de la innovación y el PIB crecen de forma sostenida y articulada en el tiempo.
Clasificación JEL: O30, O31, O32, O57.

Palabras clave: patentes, crecimiento económico, modelo de cointegración, México, TLCAN, países europeos y asiáticos.

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1. Introduction

This research aims, first, at a comparative analysis of the dynamics of research and development as a percentage of gross domestic product (R&D/GDP), resident patents filed in intellectual property offices (IPOs), exports of high-value goods (VATs) and the innovation and economic growth patterns in the three USMCA countries and selected countries of the European Union and Asia in the period 1990-2021. On the other hand, we compare the effects of R&D and GDP on resident and nonresident patenting and both indicators in VATX in the three USMCA countries and selected countries of the European Union and Asia over the period 1990 - 2016. We are interested in answering the following questions: i) how are the dynamics of innovation characterized using the variables of R&D and resident patents applied; ii) what is the impact of R&D effort and resident and non-resident patents applied on the dynamics of VATX relative to total exports in each country of the three study regions? and iii) how different are the patterns of innovation economic growth among the countries of the three regions?

As a hypothesis, it is expected that between trade regions there will be differentials between countries in the dynamics of R&D and patents, crucial variables for building learning capabilities, absorbing spillovers from the technological frontier and developing innovation capabilities. Therefore, the higher intensity and growth of these variables will have a positive effect on the increasing dynamics of exports of high value-added technological goods, which in turn suggests differentials in economic growth performance between countries.

The paper is divided into five sections. The second section summarizes the theoretical background. The third section shows the dynamics of innovation, high-tech exports and growth in the countries selected for the study. The fourth section estimates the impact of R&D/GDP (%) and resident patent applications on exports of high-value technological goods through an ARDL model, as well as the interaction between the variables of patents and economic growth, and the variables as a whole. In addition, based on the dynamics of the growth rates of resident patents and GDP, patterns of innovation and economic growth are analyzed. Finally, the last section presents some concluding remarks.

2. Theoretical background

Identifying the factors that influence economic growth is a topic of great importance for economic theory. In this sense, knowledge and its spillovers are increasingly recognized as determinants of economic growth (Audretsch & Keilbach; 2011; Antonelli, 2017). Thus, science and innovation have become essential factors for technological development in industrialized countries and in some developing countries (Fukuda, 2020; European Commission, 2013; OECD, 2005). Various studies show that new technologies and their application in production activities influence the transformation of economic structure and improve productivity and innovation policies, thus contributing to economic growth and development, such as the case of Cheng et al. (2023), who analyze the impact of digital transformation on total factor productivity of enterprises from 2007 to 2020 in China. On the other hand, Mariani et al. (2023) focus on identifying the technological, economic and social factors that lead firms and organizations to adopt artificial intelligence (AI) for innovation. In turn, Venturini (2022) aims to estimate the impact of the generation of new technologies, called intelligent technologies (artificial intelligence -AI-, flexible automation, additive manufacturing, big data, etc.), on productivity spillovers in developed countries. However, the link between innovation and productivity is not necessarily linear, but the result of a more complex process, referring to the innovation-productivity paradox (Ortega-Argiles & McCann, 2021). Akcigit (2022) focuses on analyzing not only the impact of innovation on economic growth, but also its subsequent effects on social mobility and human happiness, an indicator of social welfare. Previously, Aghion et al. (2016) used a Schumpeterian model to analyze the relationship between creative destruction and subjective well-being, finding a clear positive effect when controlling for unemployment.

Schumpeter (1939 and 1942) is undoubtedly credited with contributing a theory of growth that emphasizes the importance of entrepreneurs willing to compete in the marketplace through innovation. In examining the relationship between innovation and economic growth, Schumpeter notes that innovations occur and cluster cyclically and introduces the idea of creative destruction.

One contribution that extends Schumpeter's contribution (1947) to the understanding of the role of innovation in economic growth is the recognition of the externalities of technological knowledge as an opportunity to generate new knowledge. In the absorption process, knowledge embedded in previous innovations is used, beyond the knowledge appropriated by inventors or firms that finance R&D and/or patents (Antonelli, 2017).

The determinant influence of innovation in the development of economic growth has been present in several studies (Nelson, 2007; Verspagen, 2007; Metcalfe, 2002; Cantwell, 2000; Mowery and Nelson, 1999; Nelson, 1998; Nelson and Winter, 1982; and Nordhaus, 1969). Also, from a heterodox perspective, Aghion and Howitt (1998); Aghion, Akcigit and Howitt (2014) have provided continuity to Schumpeter's work. These authors model growth through creative destruction to explain the competitive process, in which entrepreneurs are constantly searching for new ideas that render the ideas of competitors obsolete.

There is a large body of literature linking economic growth to technological change and several studies agree that this variable explains sustainable growth. Intellectual property rights (IPRs) have therefore been identified as an incentive for innovation and can have a positive impact on economic growth. To the extent companies are innovating to maintain or increase their market share, the protection of IPRs is crucial to promote long-term growth (Gambardella, 2023; Hall, 2019; Gould and Gruben, 1999).

In an environment of constant openness and globalization in which there is a marked worldwide growth of scientific and technological knowledge flows (and their respective externalities), patent systems and, in general, intellectual property rights (IPR) acquire a strategic character for firms so that they can ensure rates of return on investment in research and development (R&D) and innovation (Archibugi & Filippetti, 2010). The limits set by property rights to the use of inventions generate externalities that are inherent to innovation (Griliches, 1979; Henry & Stiglitz, 2010). However, studies on the impact of the adoption of lax or strong intellectual property systems on economic growth has been very controversial and is still inconclusive; several empirical studies indicate that the effects of intellectual property systems on economic growth may vary as a function of technological effort, as measured by R&D expenditure (Khouilla & Bastidon, 2023; Kim et al, 2012; Levin, 1988).

Institutional policies have been proposed to harmonize the strengthening of IPRs at the global level, in the context of the growth of international trade linked to the opening of economies, where the creation of scientific and technological knowledge and the absorption of its spillovers are becoming strategic activities. In this regard, several questions have been raised by scholars and IP policymakers: How strong should IPRs be to promote economic growth? Can the harmonization of strong IP systems ensure the economic growth of countries despite the significant differences that exist between them? The debate on this issue is still inconclusive.

Taking patents as an indicator of innovation (Nagaoka et al. 2010; OECD, 1982; 1997; Archibugi, 1992; Scherer, 1965, 1982), several studies have focused on empirically demonstrating the causal relationship between patents and economic growth (Nguyen & Doytch, 2022; Mohamed et al, 2022; Sripibool, 2010; Hu and Png, 2010; Park, 2008; Atun, Harvey and Wild, 2006; Gould and Gruben, 1999; Park and Ginarte, 1997; and Taylor, 1994).

With respect to Mexico, two previous studies have attempted to determine whether there is a long-run relationship between patents and economic growth. The first (Guzmán et al., 2012) finds that the marginal change in the number of patents granted by the USPTO to Mexican patentees from 1980 to 2008 positively affects the GDP growth rate. However, the GDP growth rate does not affect the dynamics of the number of patents. In fact, they show that a shock to the number of patents negatively affects the rate of real economic growth. The second (Guzmán, et al., 2018) also examines the same issue, but with resident patents granted at the Mexican Institute of Industrial Property (IMPI) between 1991 and 2015. The results confirm the previous study: shocks to the number of patents and GDP growth have only a transitory effect on the increase in patents (ΔPATI), while this shock has a substantial negative and perhaps permanent effect on the increase in economic growth (ΔGDP).

The role of IPRs in promoting R&D and their impact on the development of capability absorption and the generation of new technological knowledge has also been empirically analyzed (Nguyen & Doytch, 2022; Cimoli et al, 2014; Kim, 2008; Cohen, Nelson, and Walsh, 2000; and Griliches, 1984 and 1998). Some papers have emphasized international knowledge spillovers and discussed whether developing countries are able to absorb frontier technology and catch up (Eugster, et al, 2022; Coe and Helpman, 1995; Coe, Helpman and Hoffmeister, 1997; Helpman, 1997). Although Latin American countries are not characterized by being innovative, Aali & Venegas-Martínez (2016) find that the more representative countries continue to have a positive impact on real GDP per capita and, consequently, on TFP through increases in R&D spending, patents, and high-tech exports (Aali & Venegas, 2016).

Despite the positive influence that the adoption of strong intellectual property systems theoretically implies for innovation and economic growth, the empirical evidence remains limited and generally inconclusive. Although it is widely accepted that the impact of the Agreement on Trade-Related Aspects of Intellectual Property (TRIPs) on industry may vary with the level of technological development, the benefits of stronger IPR protection seem to increase with income and technological intensity (Lall, 2003).

Two crucial variables that influence the generation of patents are: technological activity and economic activity. On the one hand, the intensity of technological activity is accompanied by the R&D effort that stimulates innovation and the number of patents; but in turn, patents, by creating certainty in the appropriation of the benefits of innovation, contribute to encouraging greater R&D spending. On the other hand, the level of economic growth should lead to a dynamic based on innovation and the generation of patents.

Therefore, in developing countries with greater technological specialization, IPRs are of greater importance and these countries will be the main beneficiaries of strengthened IPRs. In contrast, in poor and developing countries, technological activity is more oriented towards learning how to use technologies. In a strategy based on imitation, little importance is attached to patents as a stimulus for innovation. However, in countries characterized by reverse-engineering-based imitation, the number of patents (although small) can boost firms in the initial stages of building technological skills; this was the experience of Korea and Taiwan where strong local firms were developed in sophisticated industries (Cimoli, Ferraz and Primi, 2005). Consequently, the advantages that countries can take from the strengthening of IPRs (patents) in terms of the appropriation of invention and the diffusion of technological knowledge seem to depend on the economic and institutional conditions of the countries. Likewise, Gould and Gruben (1996) find that IPRs significantly determine economic growth and especially to a greater extent in more open economies. Falvey, Foster and Grenaway (2004) show that IPRs are positively and significantly related to growth in both high- and low-income countries, but not in middle-income countries.

3. Dynamics of R&D/GDP (%), resident patents applications and high-tech exports of North American, European Union and Asian countries

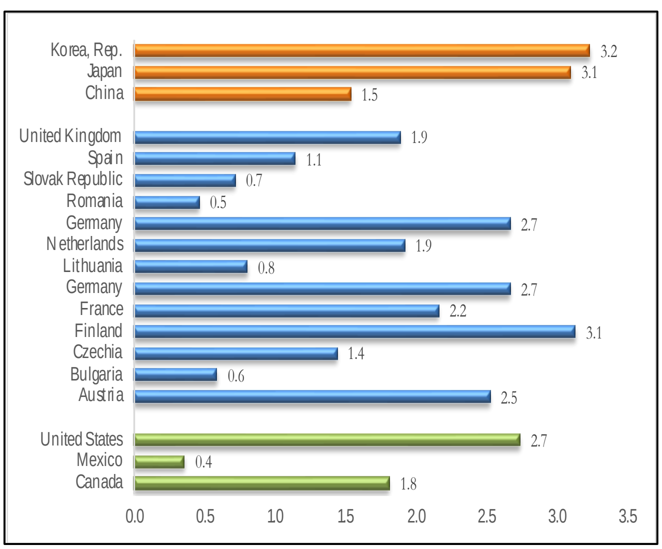
In this section we characterize the dynamics of three indicators related to innovation, which, depending on their performance, are expected to have an impact on economic growth. The first is the percentage of research and development expenditures as a percentage of gross domestic product (R&D/GDP); the second is the number of patent applications filed by residents; and the third is the number of high-tech exports. These allow us to understand the innovation dynamics of selected countries in the three study regions and, in turn, the impact on the countries' economic growth.

Research and development activities are essential to generate new ideas that provide solutions to industrial engineering processes or create new products that meet consumer needs (Baldwin, 1997; Nelson, 1987; Mairesse & Mohnen, 2004), but they also allow intra-firm transfers that contribute to knowledge spillovers (Teece, 1977). It is of great importance that countries' R&D efforts are valued through their science and technology policies, industrial policies aimed at achieving sustainability of innovation and a climate conducive to transitions to new technological paradigms. The degree of R&D intensity, supported by significant amounts of investment, highly specialized human capital and skills in learning, absorbing knowledge and generating new ideas, describes socio-technical systems in an environment of continuous innovation (Sarpong et al, 2023). R&D/GDP is thus an indicator that allows for a comparative dimension across countries. This indicator is often used in international comparisons to show the importance that countries attach to innovation activities and technological progress (OECD-FECYT, 2003). Inventions with the potential for industrial scale-up are patented so that inventors have intellectual property rights and can recoup their investment plus the profits from the novelty.

In the North American region, where the United States, Canada and Mexico have been grouped in the NAFTA free trade area since 1994 and currently in the USMCA, the United States is well ahead of Mexico and, to a lesser extent, Canada in this R&D/GDP indicator. On average between 1996 and 2021, the United States allocates 2.7% of its GDP to R&D activities, which would allow it to be at the technological frontier in several manufacturing sectors; the significant increase (over 3%) stands out. Canada, on the other hand, spends an average of 1.8%. Finally, Mexico recorded 0.4% over the same period, although the decline was less than 0.3% in recent years, further widening the technological gap with the United States.

For this study, we selected thirteen out of twenty-seven European Union countries, seven in Western Europe (the United Kingdom left the European Union after Brexit) and six in Eastern Europe. Across the European Union countries, there are significant differences, but also convergences, in R&D expenditure as a percentage of GDP. The countries lagging furthest behind are those in Eastern Europe, with Romania, Bulgaria and the Slovak Republic all averaging less than 1 per cent. However, there are other countries that have increased their R&D expenditure to over 1% of GDP over time, such as the Czech Republic and Lithuania. Among the Western European countries, Germany, Austria and France converge with an average of 2.7-2.2% of R&D expenditure as a percentage of GDP from 1996 to 2021, surpassed by Finland with 3.1%, reaching up to 3.7% in 2008-2009, when Nokia was at its peak.

Finally, the three Asian countries selected for this study are Japan, China and South Korea. Among these countries, the R&D effort relative to GDP is remarkable. The Republic of Korea stands out with an average expenditure of more than 3% over the period 1996-2021, with a growth rate of 3.3%. In the last five years, the R&D/GDP ratio was above 4% and will be close to 5% in 2021. China accounts for 0.56% of this indicator.



Country/Region	2021
East Asian	
China	2.4
Japan	3.3
Korea, Rep.	4.9
European Union	
Austria	3.3
Bulgaria	0.8
Canada	1.7
China	2.4
Czechia	2.0
Finland	3.0
France	2.2
Germany	3.1
Japan	3.3
Korea, Rep.	4.9
Lithuania	1.1
Netherlands	2.3
Germany	3.1
Romania	0.5
Slovak Republic	0.9
Spain	1.4
United Kingdom	2.9
North America	
Canada	1.7
Mexico	0.3
United States	3.5

Figure 1. R&D expenditure as percentage of GDP in East Asian, European and North American countries. Average from 1996-2021 period (%)

Source: own elaboration based on World Bank.

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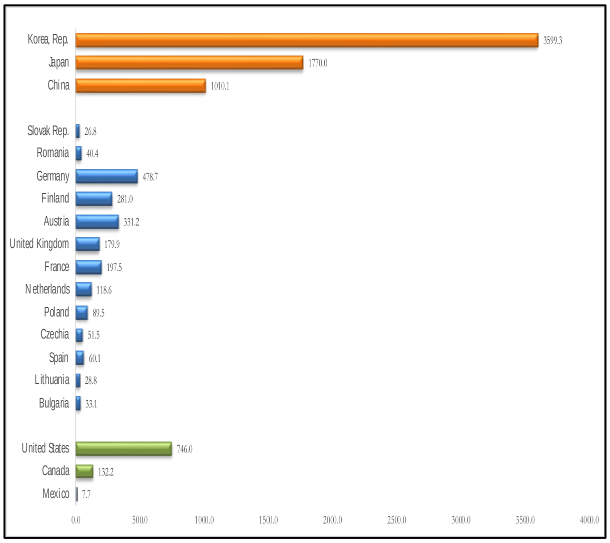
It is interesting to compare how each country's R&D effort is reflected in the growth of resident patent applications to their respective intellectual property offices. However, one should take into account the strength of the patent system, which could explain part of the performance of patent-protected inventive activity (Kotabe, 1992; Sakakibara, 2001). For Archibugi and Coco 2004, a patent is codified knowledge in the form of a technological innovation created for commercial purposes for the benefit of the patenting firm.

We considered it appropriate to weight the number of patents by the size of the country's population. We therefore divided the number of patents by the million inhabitants in each year. We then estimated the average of this indicator over the period 1997-2021. See Figure 2, which also shows the number of patents per million inhabitants in 2021 and the total number of patents in that year.

Among the three regions, East Asia stands out in terms of patented inventive activity. The Republic of Korea leads the ranking with an average of 3,599.3 patent applications per million inhabitants between 1997 and 2021, followed by Japan with 1,770 and China with 1,100.1. However, China accounts for two-fifths of the total number of patents among the countries selected for the study, with an average annual growth rate of 20.8% over the period. It registered almost one and a half billion patent applications in 2021. The Republic of Korea has maintained a high level of patent applications since 1997, with an average annual growth rate of 4.15%. Japan, on the other hand, will see its rate fall by an average of -10.4% per year between 1997 and 2021 (see Figure 2).

Among the countries of the European Union, Germany leads with 478.7 patents per million inhabitants from 1997 to 2021 and almost 40 thousand patent applications in 2021. Austria and Finland stand out with lower levels (see Figure 2).

Finally, in the North American region, the United States is the undisputed leader, with an average annual rate of 3.3% between 1997 and 2021, an average of 746 patents applications per million inhabitants over the same period and more than a quarter of a million patents in 2021 (see Figure 2). In particular, the United States and the Republic of Korea have similar levels of patenting in 2021. In contrast, Mexico lags far behind with an average of 7 patents per million inhabitants over the same period, although it records an average increase of 4.16% in patents per year, which explains the 1,117 patent applications in 2021. Canada, on the other hand, also has a significant gap with the United States, but not as large as Mexico's.



Country/Region	2021, Patents App./Mll.Inh	Total Patents App., 2021
East Asian		
China	1010.1	1,426,644
Japan	1770.0	222,452
Korea, Rep.	3599.3	186,245
European Union		
Bulgaria	33.1	165
Lithuania	28.8	81
Spain	60.1	1,308
Czechia	51.5	541
Poland	89.5	3,377
Netherlands	118.6	2,080
France	197.5	13,386
United Kingdom	179.9	11,592
Austria	331.2	2,966
Finland	281.0	1,557
Germany	478.7	39,822
Romania	40.4	772
Slovak Rep.	26.8	146
North American		
Mexico	7.78	1,117
Canada	132.20	4,710
United States	746.00	262,244

Figure 2. Patents applications per million inhabitants in East Asian, European Union and North American countries. Average from 1997-2021 period and patents applications, 2021.
Source: own elaboration based on World Bank.

Among the countries in the three regions, almost a quarter or more of their total exports between 1997 and 2021 will be of high technological value. In East Asia, Korea and China stand out. From the European Union, the United Kingdom, the Netherlands and France stand out. In the case of North America, it is the United States, whose HTX account for only a quarter of the total. Mexico and Canada, with lower levels, also account for a significant percentage.

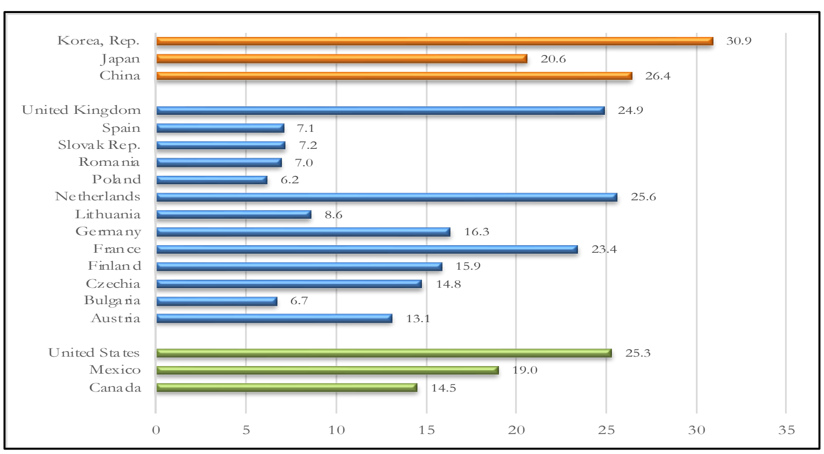


Figure 3. Exports of technology-intensive goods/total manufacturing exports by regions (%). Average in 1997-2021 period.
Source: own elaboration based on World Bank.

Table 1. Statistics

	R&D expenditure as percentage of GDP					Patents applications by residents				
	Mean	*Standard Deviation*	*Maximum*	*Minimum*	*Kurtosis*	*Mean*	*Standard Deviation*	*Maximum*	*Minimum*	*Kurtosis*
Austria	2.5700	0.5118	3.2563	1.6613	-1.2866	2,264.16	278.8839	2,966.00	1,815.00	0.4063
Bulgaria	0.5971	0.1605	0.9566	0.4268	-0.7916	249.28	45.7416	394.00	165.00	3.2441
Canada	1.8329	0.1276	2.0292	1.6155	-1.2594	4,449.96	526.4032	5,522.00	3,344.00	-0.4136
China	1.5734	0.5632	2.4326	0.6389	-1.2269	505,215.88	529,390.1348	1,426,644.00	12,672.00	-1.2205
Czechia	1.4700	0.3685	1.9960	0.9988	-1.7098	707.00	129.6248	984.00	526.00	-0.8470
Finland	3.1668	0.3257	3.7494	2.6170	-0.8835	1,815.68	401.4663	2,579.00	1,260.00	-0.7333
France	2.1547	0.0747	2.2819	2.0155	-1.1575	14,067.32	563.4844	14,748.00	12,771.00	-0.6463
Germany	2.6781	0.3110	3.1678	2.1756	-1.3018	47,322.00	2,381.0703	51,736.00	39,822.00	3.9018
Japan	3.1492	0.1689	3.3994	2.7704	-0.4756	309,097.00	52,345.7381	384,201.00	222,452.00	-1.5019
Korea,Rep.	0.8154	0.1778	1.1336	0.5020	-0.7298	130,645.12	43,304.3102	186,245.00	50,596.00	-1.1236
Lithuania	0.4011	0.0897	0.5524	0.2839	-1.3218	89.80	20.5811	134.00	62.00	-0.5092
Mexico	1.9140	0.1981	2.3218	1.6435	-0.5453	881.16	376.9658	1,555.00	420.00	-1.6125
Netherlands	1.1537	0.1920	1.4293	0.7797	-0.8654	2,298.80	159.8166	2,585.00	2,079.00	-1.0057
Poland	1.8751	0.4589	2.9314	1.5576	0.7291	3,145.40	895.6441	4,676.00	2,028.00	-1.6769
Romania	2.7589	0.2730	3.4678	2.4705	1.9262	1,060.88	231.6319	1,708.00	772.00	1.3659
SlovakRep.	3.3460	0.9454	4.9301	2.0626	-1.4494	206.92	28.9236	259.00	146.00	-0.3677
Spain	0.8139	0.2804	1.4359	0.5388	-0.0640	2,671.28	700.9169	3,632.00	1,288.00	-0.2606
United Kingdom	0.4542	0.0601	0.5703	0.3645	-0.8319	16,585.00	3,146.6684	22,050.00	11,592.00	-0.9952
United States	0.7129	0.1974	1.1785	0.4482	-0.3729	229,870.64	53,922.6373	295,327.00	119,214.00	-0.8722

Exports of technology-intensive goods/total manufacturing exports (%).					
	Mean	*Standard Deviation*	*Maximum*	*Minimum*	*Kurtosis*
Austria	13.0712	1.7775	16.3508	10.8995	-1.1736
Bulgaria	6.7485	2.7620	11.2951	2.8718	-1.2276
Canada	14.5462	1.2557	17.7294	12.0937	0.4285
China	26.3709	5.3013	31.5451	13.1242	0.6681
Czechia	14.7653	3.9689	22.5793	8.0596	-0.4610
Finland	15.8596	6.7690	27.3610	7.2145	-1.6707
France	23.4185	2.8012	28.1846	18.4780	-1.0335
Germany	16.3424	1.3671	18.6258	13.3047	-0.3936
Japan	20.6243	4.0933	28.6887	16.6888	-1.2737
Korea,Rep.	8.6454	3.4649	12.7802	3.2906	-1.5375
Lithuania	19.0049	2.3073	22.4514	14.6869	-1.2658
Mexico	25.6102	4.8604	35.8066	19.2488	-0.9583
Netherlands	7.0676	0.8717	9.3926	5.1073	1.8476
Poland	24.8904	4.5928	34.0192	18.4635	-0.5223
Romania	25.2779	6.3326	34.2582	17.7769	-1.8258
SlovakRep.	30.8966	3.1057	36.3907	25.7213	-0.7336
Spain	6.1650	3.1770	10.7744	2.6183	-1.6582
United Kingdom	6.9522	3.3014	11.9370	1.2057	-1.3734
United States	7.1872	2.9391	11.7654	3.2125	-1.5623

The relationship of R&D/GDP to patents in North America, the European Union and East Asia

A useful analytical tool is to look at the dynamics of the relationship between R&D/GDP growth and patents in each country/region over time, as it allows us to identify the extent to which R&D efforts lead to inventions that are patented, i.e. the efficiency of the R&D sector. Figures 3, 4 and 5 therefore show the evolution of these two innovation indicators by region.

Looking at the USMCA region, the graph shows very different innovation patterns across countries. On the one hand, the United States shows similar growth rates in R&D/GDP spending and resident patent applications, with patent growth in some years even higher than R&D spending; the United States continues to grow moderately but sustainably. The growth rates are not high because they start from large initial amounts. The concentration of these two indicators suggests a very consolidated pattern of innovation activity in the United States. In Canada, on the other hand, the growth rates of both indicators are not sustained over time, although in some years they exceed those of the United States. Finally, Mexico's growth rates in R&D and patent applications over the period are very dispersed; although in the second half of the 2000s growth in both indicators is positive, taking into account an initial low point, research effort and its results later show an erratic and unarticulated trajectory (see Figure 4).

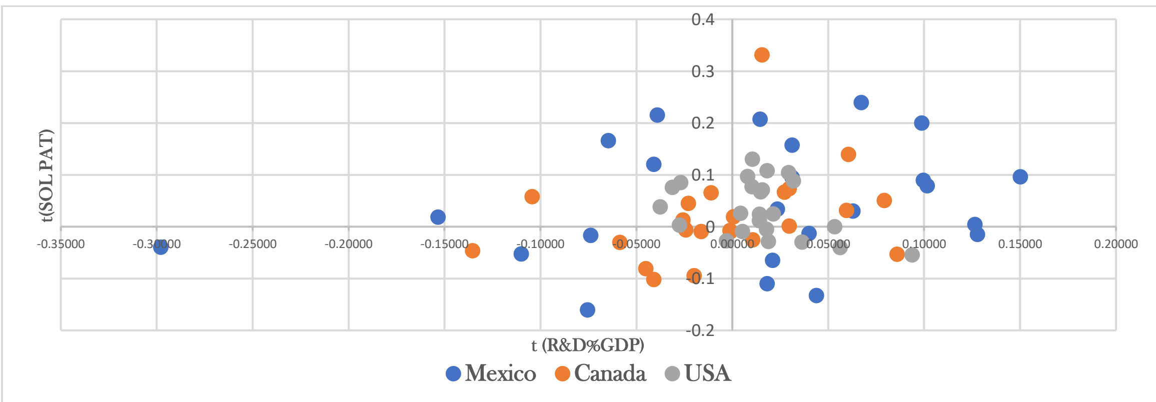


Figure 4. Growth in R&D/GDP and patents applications by residents in USMCA countries, 1990-2021.

Source: own elaboration based on World Bank.

There are also differences in the growth rates of R&D expenditure/GDP and patents among the countries of the European Union, especially among some Eastern European countries such as Romania, Slovakia and Lithuania. Other countries, such as Poland, the Czech Republic and Spain, show a converging trend towards the innovation leaders: Germany, France, the United Kingdom and Austria. Although the United Kingdom is growing faster in R&D, Germany is growing faster in patents, with significant research and development efforts.

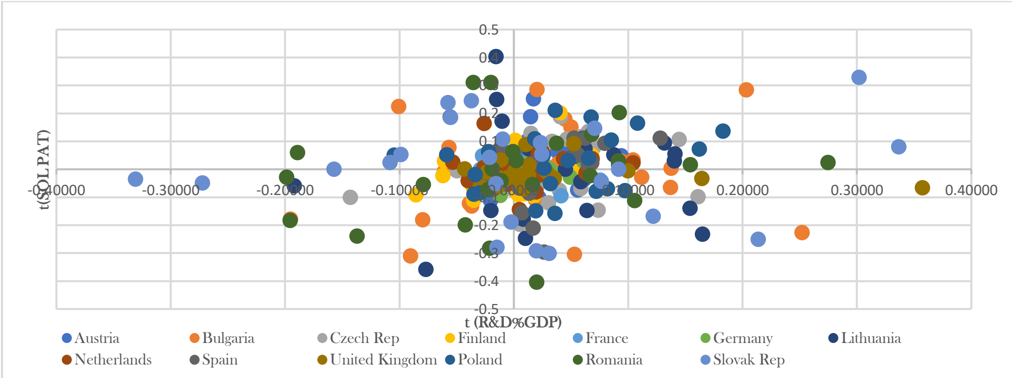


Figure 5. Growth in R&D/GDP and patents in European Union countries, 1990-2021
Source: own elaboration based on World Bank.

The three Asian countries selected for this study are Japan, China and South Korea. Japan is known for its technological catch-up and convergence with industrialized countries. As a result, growth rates in R&D and patents are high and sustainable. South Korea, on the other hand, not only manages to converge with Japan's growth rates, but also outperforms Japan in terms of R&D growth. The logarithmic growth achieved by China in the two variables that are part of the innovation process is undoubtedly remarkable. With such dynamism, this Asian country is expected to take the lead not only in the Southeast Asian region, but also in the world in the coming years.

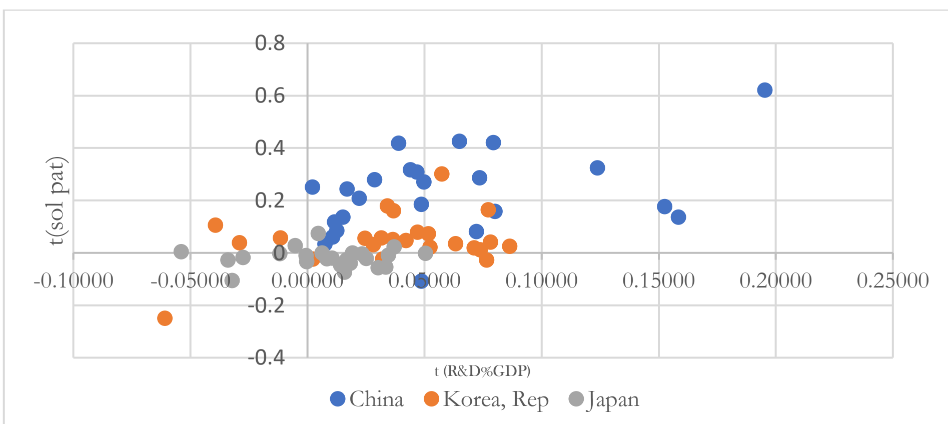
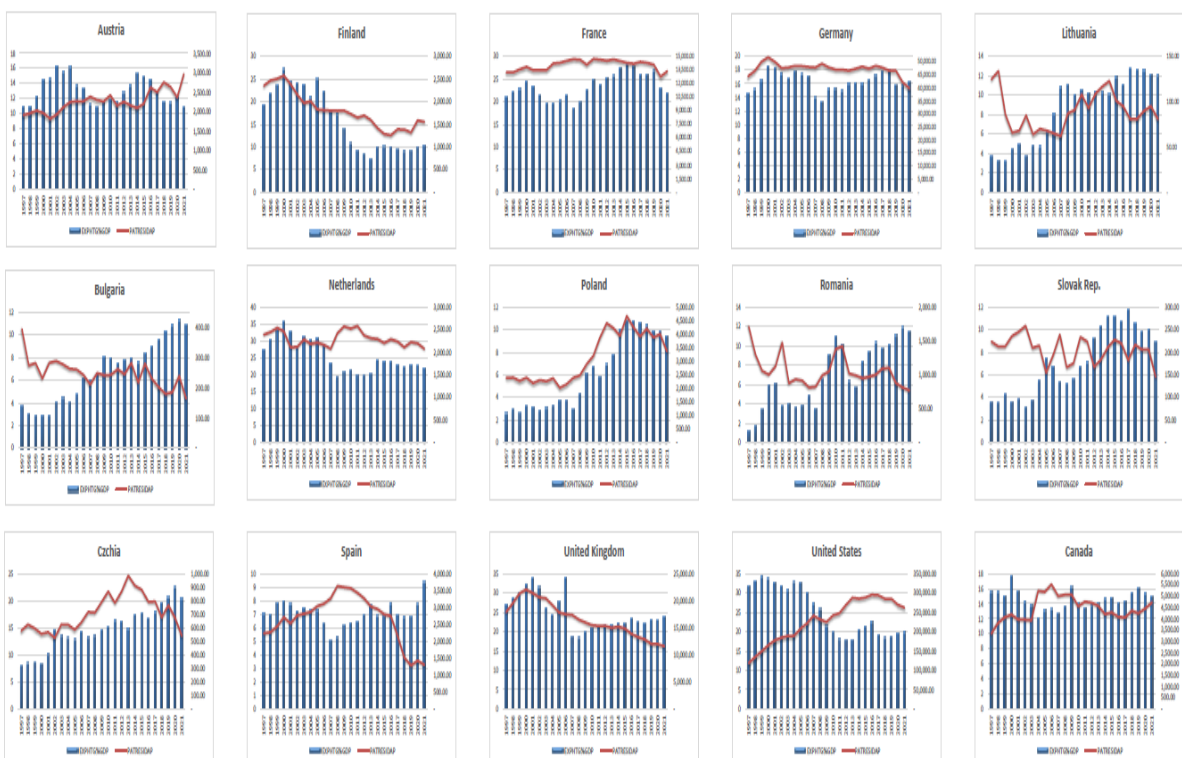


Figure 6. Growth in R&D/GDP and patents in Asian countries, 1990-2021
Source: own elaboration based on World Bank.

Technology-intensive goods and patents filed by residents' relationship in North America, the European Union and East Asia

When analyzing the evolution of exports of technology-intensive goods as a percentage of total manufacturing exports and the number of patents filed by residents of the intellectual property offices of North American, European Union and Asian countries over the period 1997-2015, three main trends can be observed. The first is that of countries with an increasing trend in patents but a decreasing trend in exports of technology-intensive goods as a percentage of total exports, such as the United States; with a much lower level of both indicators, this would be the case of Mexico. The second corresponds to countries that have increased both indicators; with a higher level in both is China, the Eastern European countries with a lower level (Czech Republic, Lithuania, Bulgaria, Poland, Slovakia). On the other hand, among the Western European countries, Germany stands out more for patents, but France for exports of technology-intensive goods/total exports. Finally, the third group consists of countries which, after an excellent performance in exports and patents, have recorded a significant decline in recent years; we find here Japan and Finland.

The huge differences among North American countries, previously grouped in NAFTA, now in the USMCA, were and are related to the technological gap, the efforts made by countries in terms of net capital investment, average labour productivity and total factor productivity. Above all, however, the variables that form the backbone of the knowledge and innovation economy. Intellectual property rights are recognized as key to the decision to invest in innovation activities to foster economic growth in knowledge economies. Differences in R&D expenditure as a percentage of GDP, human capital formation per million inhabitants, technology transfer and exports of technology-intensive goods can therefore be crucial in fostering virtuous circles that contribute to innovation, economic growth and hence to the well-being of the population. Expectations of catching-up and convergence were considered as possible scenarios. Mexico would have significant externalities from trade flows in high-tech goods. However, Mexico lacked a strategy to substantially increase its efforts to develop scientific and technological capabilities.



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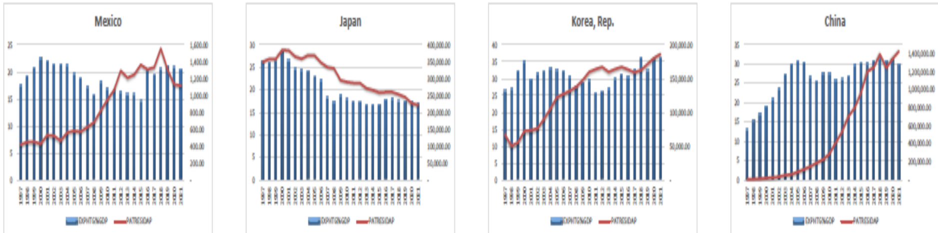

Figure 7. Exports of technology-intensive goods/total manufacturing exports (%) vs. number of patents by residents of selected North American, European Union and Asian countries, 1997-2021
Source: own elaboration based on World Bank.

4. Impacts of R&D/GDP (%), and patents applications on the exports of high-value technological goods through an ARDL model. Innovation and economic growth patterns, 1996-2016.

As proposed methodology, we have a Panel ARDL (1,1,1,1) model was estimated to explain the changes in exports of the countries under study NAFTA (now USMCA): Canada, United States, and Mexico; European Union: Belgium, Bulgaria, Czech Republic, Denmark, Italy, France, Lithuania, Netherlands, Poland, Romania, Slovakia, Spain, Sweden, Switzerland, and United Kingdom; Asia: China India, Japan, and Korea) by means of changes in exports of high-tech goods as a percentage of past exports, resident patents, non-resident patents, and changes in R&D expenditures as a percentage of GDP over the period 1997-2015 with annual data.

According with Pesaran, Shin and Smith (1999), a cointegration form of a simple ARDL model can be used to construct the Pooled Mean Group estimator, which allows that the intercepts, short-run coefficients and cointegration terms differ across cross-sections.
The resulting model specification is:

$$\Delta y_{i,t} = \phi_i EC_{i,t} + \sum_{j=0}^{q-1} \Delta X'_{i,t-j}\, \beta_{i,j} + \sum_{j=1}^{p-1} \lambda_{i,j} \Delta y_{i,t-j} + \epsilon_{i,t},$$
$$EC_{i,t} = y_{i,t-1} - X'_{i,t}\theta$$

Where:
$\Delta y_{i,t}$ is the annual change of exports for the country i during the year t.
EC_i is the error correction term to the long run equilibrium.
$\Delta X'_{i,t-j}$ are lagged explanatory variables.
ϕ_i, $\beta_{i,j}$ and
$\lambda_{i,j}$ are parameters to be estimated.

The estimated coefficient for the cointegrating relationship adjustment is highly significant for all the countries included in this analysis, inclusive at the 1% level, but only in the case of France is observed a 5% significance level. Special importance is the cases of China and United States with positive coefficients and low values, but highly significance (even at 1%). Germany, Czech Republic, United Kingdom and Korea stand out by the magnitude of the coefficient value (-0.83, -0.82 -0.98 y -1.07, respectively); implying a very fast adjustment to the long-run equilibrium relationship when there is a deviation of it.

Relationship between changes of resident's patents and VAT exports

For the case of Bulgaria, Japan, Netherlands, United States, Romania, and Korea we find positive coefficients. It suggests that export variations are linked positively with the change of the number of resident patents. Even if the coefficients oscillating during the period of some countries as Austria, Canada, China, Czech Republic, Germany, and the United Kingdom show a positive relationship among these variables. The rest of countries show a negative sign, as Mexico.

Relationship between changes of non-resident patents and VAT exports

Concerning the non-resident patents face to export changes, Finland, Germany, Netherlands and Poland suggest a direct and positive relationship. Meanwhile, China, Japan, Lithuania, United States, Romania and Slovakia have an inverse relation between both variables. Other countries show an erratic dynamic; sometimes oscillate at a positive relationship and other time in a negative one along the period.

Relationship between R&DE/ GDP and VATX growth rate

Regarding China, Finland, Mexico, Spain, Slovakia and United States, we see a positive relationship between the variables, notably high in the American case. Different dynamic it is shown by Bulgaria, Germany, Japan, Lithuania and Korea, with inverses changes in R&DE/GDP and exports. Concerning Canada, France and the United Kingdom we don't find a statistical significance in this relation, although the sign are positive for the two first countries and negative for the last one. Czech Republic has both signs.

The trend in the VAT export growth rate

The deterministic trend coefficient has a highly significance in all the cases, with exception of Korea (only 10%). Regarding the sign, it is positive for Bulgaria, Canada, Czech Republic, France, Lithuania, United States, Poland, Romania, Slovakia and Korea. The other countries oscillate between a positive or negative relationship.

Germany, the United Kingdom and, to a lesser extent, France stand out among the European countries. It should be noted that although Germany and France have not reached the level of the number of patent applications of the United Kingdom, while the former have maintained a growth trend. The same applies to the average R&D expenditure as a percentage of GDP, where France and Germany have the same average (2.7), while the UK maintains a lower average (1.9). In fact, in the United Kingdom, the percentage of exports of high value-added goods has also declined in recent years. This is interesting because in the set of variables, the case of the United Kingdom and Germany, in the ARDL model, shows a relationship that alternates between positive and negative, but significant, the relationship between the variables of patents applied for by residents in period t and t-1, and exports of high value-added goods. It should be noted that the three countries are known for

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their strong GDP systems and for being exporters of high-tech goods. For the rest of the countries, although they have made efforts to increase their levels of patents applied for by residents, as well as R&D spending, the levels of these variables and their exports of high-tech goods, the ARDL model shows that the effects of these variables have either positive or negative effects overall.

Among the countries of the Asian bloc, the case of China is noteworthy, since it has higher growth rates in R&D expenditures and has also achieved significant growth rates in the number of resident patent applications, and its level of exports of goods of high technological value has maintained a growth trend. However, it is also important to highlight the important role played by the country's IPR policy, which remained weak until recent years, when it gradually signed and accepted international agreements to strengthen such rights. The case of Korea has also maintained this trend, although it has not reached the level of China, but in the case of Japan there has been a lower growth rate in R&D expenditure, accompanied by a decrease in VATX and patent applications. This behavior is confirmed by the panel ARDL model.

Table 2. Outcomes of effects R&D/GDP (%), resident and non-resident patents applications on the exports of high-value technological goods through an ARDL model

Country	*EC*		DX/Man$_{t-1}$		DRP$_t$		DRP$_{t-1}$		DNRP$_t$		DNRP$_{t-1}$		DR&DE/GDP$_t$		DR&DE/GDP$_{t-1}$		Constant		Trend	
Austria	-0.4568	***	0.8983	***	0.0030	***	-0.0007	***	0.0138	***	-0.0018	***	0.1697	***	-0.5294	**	6.7111	*	-0.0474	***
Bulgaria	-0.3435	***	0.1767	**	0.0122	***	0.0089	***	0.0006	***	-0.0013	***	-0.1076	***	-0.0166	*	1.4180	***	0.0813	***
Canada	-0.8697	***	0.0186		-0.0002	***	0.0002	***	-0.0002	***	0.0002	***	9.2072		5.6432		11.0436		0.0848	***
China	0.0122	***	0.1881	***	0.0000	***	-0.0000	***	-0.0001	***	-0.0000	***	0.1870	***	0.3555	***	2.1054		-0.1746	***
Czech Rep.	-0.8248	***	1.1148	***	-0.0014	***	0.0067	***	0.0004	***	-0.0010	***	-0.3472	***	0.2863	***	7.0403		0.3546	***
Finlandia	-0.4753	***	0.2057	***	-0.0035	***	-0.0137	***	0.0060	***	0.0261	***	0.5178		3.0236	**	13.6338		-0.6452	***
France	-0.2715	**	-0.1160		-0.0006	***	-0.0009	***	0.0038	***	-0.0026	***	0.8321		0.2059		5.8875		0.1047	***
Germany	-0.8391	***	0.3497	***	-0.0003	***	0.0004	***	0.0005	***	0.0002	***	-0.3647	***	-0.7306	***	18.1881		-0.1781	***
Japan	-0.1764	***	0.2462	***	0.0000	***	0.0000	***	-0.0002	***	-0.0000	***	-0.4490	***	-0.8653	***	10.2479		-0.1910	***
Korea Rep.	-1.0719	***	-0.2730	***	0.0003	***	0.0001	***	0.0003	***	-0.0001	***	-1.0534	***	-0.9007	***	37.5648		0.2069	*
Lithuania	-0.5685	***	0.1304	**	-0.0166	***	-0.0214	***	-0.0565	***	-0.0781	***	-0.0117	**	-0.0983	***	-0.0615		0.4455	***
Mexico	-0.5853	***	0.2264	***	-0.0012	***	-0.0039	***	-0.0004	***	-	***	0.0689		0.2236	**	13.6055		-0.2583	***
Netherlands	-0.3252	***	0.5108	***	0.0048	***	0.0066	***	0.0119	***	0.0069	***	-1.6600	**	0.5218		11.7941		-0.3134	***
Poland	-0.7385	***	0.2304	***	-0.0003	***	-0.0005	***	0.0004	***	0.0007	***	0.0238		-0.3655	***	0.9109	**	0.3261	***
Romania	-0.6285	***	0.2179	***	0.0045	***	0.0040	***	-0.0109	***	-0.0072	***	0.3728	***	-0.0529	**	0.1909		0.3201	***
Slovak Rep.	-0.2565	***	0.2925	**	-0.0067	***	-0.0054	***	-0.0003	***	-0.0005	***	0.1430	***	0.0981	***	0.4110		0.1353	***
Spain	-0.6571	***	0.0556	*	-0.0013	***	-0.0006	***	0.0086	***	0.0078	***	0.4192	***	0.3207	***	5.8610	**	-0.0816	***
United Kingdom	-0.9828	***	0.3169	***	0.0004	***	-0.0008	***	-0.0031	***	0.0059	***	-1.7579		-1.9622		35.2957		-0.8939	***
United States	0.0646	***	0.3032	***	0.0001	***	0.0001	***	-0.0000	***	-0.0001	***	2.5776	**	1.8320	**	-4.8197		0.1609	***

EC = Error correction term; X/Man = Export of high tech goods as percentage of total manufacturing; RP = Patents by residentes; NRP = Patents by No-residentes; R&DE/GDP = R&D expenditure as percentage of GDP.
Source: Own estimations

Innovation and economic growth patterns, 1996-2021

In European countries, differentiated patterns of innovation and economic growth can be observed in the dynamics of economic growth and resident patent applications. It should be noted that a patent application must wait for a period of time for specialized technicians to review it and determine whether it is indeed an innovation before the patent can be granted. In this sense, the impact on productivity and economic growth is delayed. However, when countries observe similar rates of sustained growth in both variables over a given period, this trend suggests a dynamic pattern of innovation.

We identify the following innovation and economic growth patterns. First, there are countries where resident patent applications grow at a higher rate than GDP. This is the case for the United Kingdom; a similar pattern is observed for France. On the other hand, we distinguish Germany, which is characterized by a continuous dynamism in the growth of resident patent applications in a similar proportion to economic growth. Finally, there are countries where both variables show growth rates that are not necessarily related and with many variations, even negative. In this group are Finland and Australia, countries that have recorded negative rates after annual increases in patent applications. At a lower level, there are Eastern European countries (Poland, Slovakia, among others) where the rates of both variables are erratic (see Fig. 8).

With some differences, but generally in agreement, we found articles that are in line with our findings. A recent study (Brodny et al., 2023), which assesses the degree of innovation of European countries using twelve proposed indicators, confirms that the "old EU member states" such as Finland, Germany and France are the best at innovating, although the top three are Luxembourg, Sweden and Denmark, countries that are not included in our study. Among the newcomers (EU new member states), Slovenia, an Eastern European country, stands out, while other emerging countries are increasing their R&D efforts to advance along the learning-imitation-innovation path (European Commission, 2023). Kacprzyk and Doryń. (2017), however, finds that while there are differences between the old and new members of the European Union, among the latter there is no significant impact. They suggest that this may be because other innovation policy issues could be affecting economic growth, and in different ways in different countries.

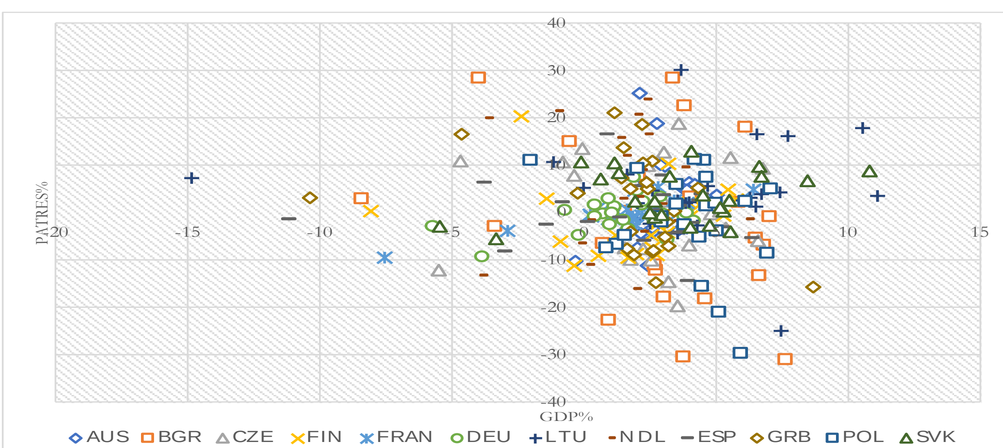

Figure 8. European Union: economic growth vs. resident patent application growth
Source: own elaboration based on World Bank.

The USMCA countries also differ in their patterns of innovation and economic growth. The United States is characterized by higher growth rates of resident patent applications than GDP growth rates. Canada, on the other hand, has lower patent growth but in some years higher GDP growth and less dispersion than the United States. Mexico, on the other hand, is quite erratic and dispersed in the growth or decline of patents and GDP (See Fig. 9).

In this sense, Dascoli y Ezell (2022) characterize North America as an eco-innovation system that is becoming increasingly diverse. Among the three countries that take part in the USMCA, there are states industrially intensive where the innovation wind is present. Among the states with the highest innovation competitiveness in the North American region are Massachusetts, California, Ontario, Maryland and Washington. The Canadian provinces of British Columbia and Quebec are also in the lower ranks. The US-Mexico border states (Nuevo Leon, Baja California, Chihuahua, and Tamaulipas) have an intensive industrial with some expectation to become innovative.

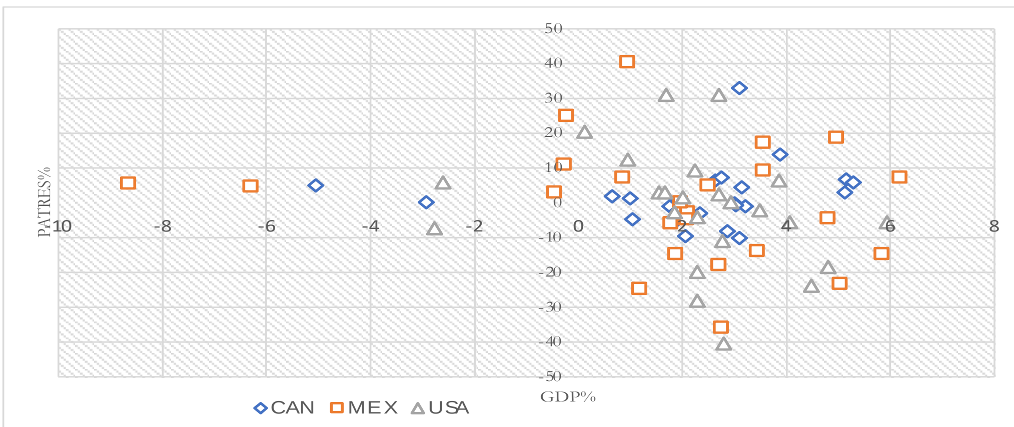

Figure 9. USMCA: economic growth vs. resident patent application growth, 1997-2021
Source: own elaboration based on World Bank.

Among East Asian countries, the Republic of Korea and China show an innovative and growing pattern of greater convergence in the dynamics of patent growth and economic growth. The latter country shows stronger increases in patent applications and GDP. Japan, on the other hand, shows a more dynamic growth of GDP and a lower growth of patents (See Fig.10).

The results of our study are consistent with several other studies. Such is the case with Cho's (2021) analysis of the performance of East Asian countries. Although the author adds that an essential aspect in such developments is the strength of their institutions, and especially the way in which agents and institutions are articulated in national innovation systems. Hu (2015) shows that the case of the Republic of Korea well illustrates the dynamic process of economic growth associated with innovation, moving from imitation to innovation, increasing its R&D efforts, scaling up in more technology-intensive industries and, consequently, in its VATX.

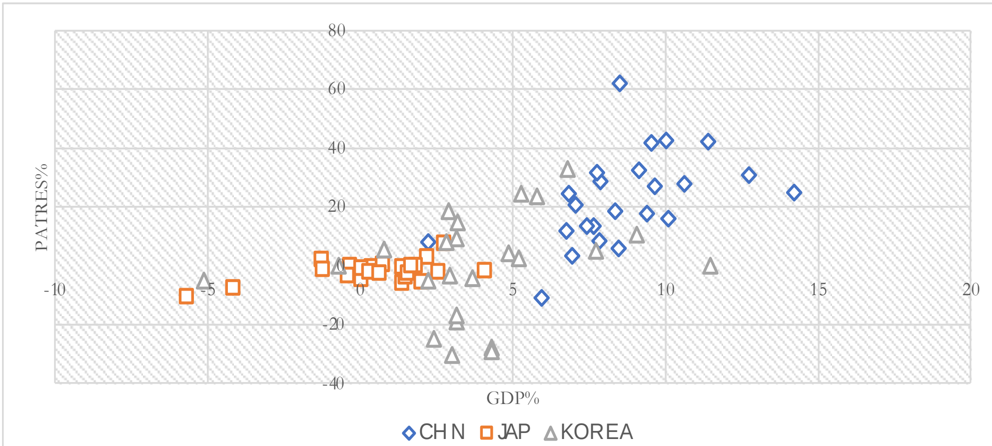

Figure 10. East Asia: Economic growth vs. resident patent application growth, 1997-2021
Source: own elaboration based on World Bank.

Now, considering the combined behavior of the four variables in 2021, GDP growth rate, growth rate of resident patent applications, research and development expenditures, and high value-added exports, the clusters shown in the following figure are derived. The dynamics of the variables under study position China as the leader. The second block with the smallest distance to China is the one marked in turquoise, where we can see the leadership of Korea, the presence of the United Kingdom and the United States, and with less dynamism, France and the Netherlands. This is in line with the previous results.

In the third block, marked in blue, Japan and Germany are on the same level. In fact, a joint analysis of their indicators suggests the presence of similar efforts, followed by Australia and Finland. In the last group are the least dynamic countries, with weak technological capabilities, as shown by their lower trend in resident patent applications and in exports of high value-added goods in general; however, in one group are Canada and Czechoslovakia, and in the weakest group are the rest of the European countries, which are making incipient efforts, as reflected in the values of their indicators.

In this last group, however, the position of Mexico stands out, which is related to the high value of its exports of high-tech goods as a percentage of its production. In this regard, it is important to emphasize that although this indicator is lower in Canada and Czechoslovakia, in terms of value, the exports of this type of goods and of the manufacturing sector of these countries are higher than those of Mexico. Thus, considering this value, Mexico paradoxically belongs to the group with the lowest dynamism.

Therefore, it can be assumed that an increasing dynamic in the variables under consideration effectively reflects greater technological capabilities, as is the case for China. Countries with weak performance also have lower technological capabilities. It is also important to note that these variables feedback on each other, creating virtuous interactions when their dynamics increase.

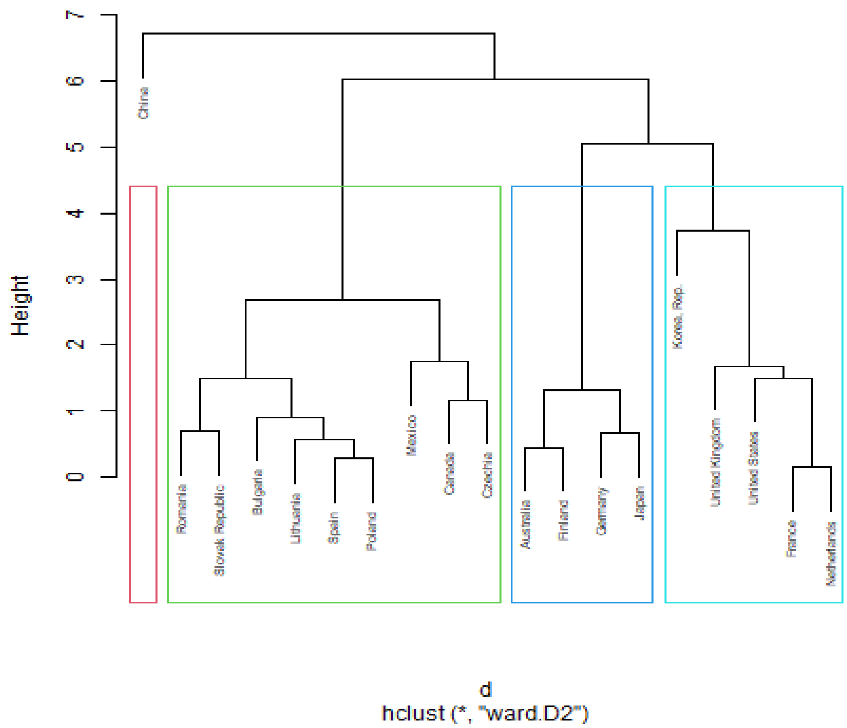

Figure 11. Cluster Dendrogram
Source: own elaboration based on World Bank and software R.

5. Conclusions

Among the regions studied, the USMCA and the European Union stand out for their respective free trade agreements. In the first case, it is limited to trade flows in goods only, but in the second case, free mobility of human capital takes place in addition to the pursuit of institutional and monetary convergence. In the third region, East Asia, there is de facto free trade. It is interesting to analyze how the differences between countries in their respective regions have evolved over the last two decades in terms of R&D effort as a percentage of GDP, resident inventive activity protected by patent applications in local offices, how these are related, and how both affect high value-added technology exports.

In the USMCA, or North American region, the enormous gaps in Mexico's R&D intensity and patent applications with respect to the United States between 1997 and 2021 have not changed but have become even more pronounced. The very low R&D/GDP spending has not allowed Mexico to take advantage of the technological spillovers offered by NAFTA, now USMCA, to develop and expand its technological and innovation capabilities. Instead of increasing, it has continued to decline. For example, the number of patents filed per million inhabitants is marginal compared to the United States and even Canada. Mexico's technological and innovative backwardness puts the United States at a disadvantage compared to the countries of East Asia, which have significantly increased their R&D efforts and have been rewarded with a strong increase in the number of patents filed, especially with their now great competitor, China.

Regarding the countries of the European Union, Germany's leadership is confirmed, but there is a growing dynamic in the variables that will have an impact on innovation, VATX and the improved economic performance of the countries of Eastern Europe.

The hypothesis of a positive effect of R&D, resident patents and non-resident patents on the percentage of VATX is confirmed for the cases of China, Japan, the United States and Germany. It is partially confirmed in a positive effect of R&D only for the cases of Canada, Mexico, China, Finland, France and the Slovak Republic. Positive effects of non-resident patents only occur for Finland, Germany, the Netherlands, Poland and Spain. Finally, only an impact of resident patents is observed for the cases of Bulgaria, Korea, the Netherlands and Romania.

Thus, it can be assumed that an increasing dynamism in the variables under consideration effectively reflects greater technological capability and ultimately has an impact on economic growth. Conversely, poor performers also have lower technological capabilities. In addition, these variables feedback and create virtuous circles as their dynamics increase.

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