Overview of the Health Economic-Industrial Complexes Worldwide: An Analysis based on the Framework Proposed by Carlos G. Gadelha

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Article

Overview of the Health Economic-Industrial Complexes Worldwide: An Analysis based on the Framework Proposed by Carlos G. Gadelha

Panorama dos complexos econômico-industriais da saúde no mundo: uma análise a partir da proposição de Carlos G. Gadelha

Panorama de los complejos económicos e industriales de la salud en el mundo: un análisis basado en la propuesta de Carlos G. Gadelha

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Abstract

The article seeks to identify the global distribution of health economic-industrial complexes based on the framework proposed by Carlos Gadelha. Its scope is limited to the technical and productive structure of these complexes and does not encompass national health systems in their entirety. To this end, the analysis is organized around three main analytical axes: the flows of productive inputs that make up these complexes, the corporate topology of major pharmaceutical and medical technology (medtech) companies, and innovation indicators, including technology parks, clusters, and patents. Finally, the article establishes a relationship between health economic-industrial complexes and the spatial production circuits of health. The result is an analytical framework that makes it possible to identify the varying degrees to which

these complexes are consolidated across different territories, without seeking to establish a ranking or provide an exhaustive classification.

Keywords: global health economic-industrial complex; productive inputs; productive spatial circuits of health

Resumo

O artigo propõe identificar a distribuição dos complexos econômicos industriais da saúde no mundo com base na formulação de Carlos Gadelha. O escopo está delimitado à estrutura técnico-produtiva, sem abranger integralmente os sistemas nacionais de saúde. Para tanto, articula três eixos principais: os fluxos de insumos produtivos que configuram o complexo, a topologia corporativa das grandes farmacêuticas e medtechs e os indicadores de inovação, como parques tecnológicos, clusters e patentes. Por fim, uma relação entre os complexos econômicos industriais da saúde e os circuitos espaciais produtivos da saúde é estabelecida. O resultado é um quadro analítico que permite identificar diferentes graus de consolidação dos complexos em distintos territórios, sem pretender constituir um ranking ou uma classificação exaustiva.

Palavras-chave: complexo econômico industrial da saúde no mundo; insumos produtivos; circuitos espaciais produtivos da saúde.

Resumen

El artículo propone identificar la distribución de los complejos económicos industriales de la salud en el mundo basándose en la formulación de Carlos Gadelha. El alcance se limita a la estructura técnico-productiva, sin abarcar íntegramente los sistemas nacionales de salud. Para ello, articula tres ejes principales: los flujos de insumos productivos que configuran el complejo, la topología corporativa de las grandes farmacéuticas y medtechs y los indicadores de innovación, como parques tecnológicos, clústeres y patentes. Por último, se establece una relación entre los complejos económicos industriales de la salud y los circuitos espaciales productivos de la salud. El resultado es un cuadro analítico que permite identificar diferentes grados de consolidación de los complejos en distintos territorios, sin pretender constituir una clasificación o un ranking exhaustivo.

Palabras clave: complejo económico industrial de la salud en el mundo; insumos productivos; circuitos espaciales productivos de la salud.

Introduction

This article examines health economic-industrial complexes on a global scale by identifying the countries that meet the criteria for possessing such complexes, according to the framework proposed by Carlos G. Gadelha. This identification is based on indicators developed from statistical data and primary sources relating to health-related industrial sectors worldwide. Drawing on these data, the study presents maps and tables depicting the distribution of industrial facilities, technology parks, clusters, and productive input flows, thereby highlighting the countries in which these complexes are concentrated.

The study thus seeks to contribute to the Brazilian literature on the subject by offering a comparative perspective and highlighting potential forms of integration among these complexes across different countries. Gadelha's original framework has provided a valuable basis for understanding both the historical and economic formation of Brazil's health economic-industrial complex and its contemporary dynamics. It has also become an important instrument for the formulation and implementation of public policies.

By identifying the countries that potentially possess such complexes, the article also seeks to situate Brazil within the global landscape, highlighting its shortcomings, opportunities, and development goals, while providing evidence to inform the formulation of national and international policies and agreements. The purpose, however, is not to revisit the conceptual debate, which has already been extensively addressed by numerous authors and culminated in the adoption of the term Health Economic-Industrial Complex (HEIC) in place of Health Industrial Complex (HIC).

As Gadelha and his research team have emphasized, this terminological shift was intended to incorporate dimensions extending beyond the strictly industrial sphere, including services, finance, trade, and innovation, thereby reinforcing the systemic interdependence of these activities. In *Perspectivas do Investimento no Brasil* [Investment Prospects in Brazil] (2009), the inclusion of the term *economic* was justified as a means of more fully integrating national innovation systems with the productive structure and overcoming reductionist interpretations

of the original concept. This reformulation underscored the circular, interdependent relationships among production, distribution, consumption, and innovation, thereby advancing a more comprehensive understanding of the political economy of health within each territory.

Against this backdrop, analyzing the global distribution of countries with specialized productive capacity in the health sector represents a significant contribution toward identifying health economic-industrial complexes on a global scale—a gap that has become increasingly evident over years of research on the subject. This analysis also provides a foundation for future studies in international political economy and on the relationship between industrial complexes and globalization, while engaging with emerging themes such as vaccine nationalism (ZHOU, 2022) and the critical geopolitics of health (INGRAM, 2009; STURM et al., 2021). Recognizing that some countries possess health economic-industrial complexes whereas others do not—and that substantial disparities exist even among those that do—may also provide a basis for broader analyses of the geopolitical role of these complexes.

Methodology

The concept of the health economic-industrial complex (HEIC) was developed by Carlos Gadelha and his research group[1] as an extension of the original formulation of the Health Industrial Complex (HIC) (GADELHA, 2003). This reformulation stemmed primarily from the need to emphasize the role of scientific innovation in the industrial sectors encompassed by the concept, while also incorporating other economic sectors that, although not directly productive, are intrinsic to the activities of the health economy. In doing so, the reformulation sought to underscore the systemic interdependence among all components of the complex.

Accordingly, the HEIC comprises a productive and technological structure in the health sector organized around identify three interconnected subsystems: (1) the chemical and biotechnological subsystem, encompassing the production of pharmaceuticals, vaccines, blood products, and diagnostic reagents; (2) the mechanical and electronics subsystem, comprising electronic and nonelectronic medical equipment, prostheses, orthoses, and medical-hospital supplies; and (3) the health services subsystem, encompassing the provision of hospital, laboratory, diagnostic, and treatment services. Together, these subsystems underscore the

[1] The first recorded use of the term Health Economic-Industrial Complex (HEIC) appeared in the report *Perspectivas do Investimento no Brasil* [Investment Prospects in Brazil] (2009), coordinated by Gadelha and funded by the Brazilian Development Bank (BNDES). The report was authored by Gadelha and his research group, comprising José Maldonado, Marco Vargas, and Pedro R. Barbosa.

interdependence between the industrial production of health-related goods and inputs and the delivery of health care, with innovation and technological development serving as the integrating force that links them (GADELHA et al., 2013). It is precisely this systemic integration that fundamentally distinguishes health economic-industrial complexes worldwide. Taking Gadelha's conceptual framework as a reference, the State System of Data Analysis Foundation (SEADE, 2016) published a classification of productive and nonproductive enterprises that provides an empirical basis for the concept, drawing on the Brazilian National Classification of Economic Activities (CNAE, version 2.0) developed by the IBGE[2] (2015). Based on this classification, the study compiled data on enterprises, their specialized productive activities, and their annual production volumes and values (ANTAS JR, 2024) to examine the role of the HEIC across Brazil in the provision of health services—particularly through Brazil's *Sistema Único de Saúde* [Unified Health System] (SUS), the country's universal public health care system—and to the development of technological innovations to address diseases and pandemics.

The HEIC has also been examined as a field of capital accumulation. One of its defining characteristics is the coexistence of domestic productive structures with local or regional linkages, alongside large corporations operating through global networks that integrate finance and industrial production. To capture the global dimension of the complex, the corporate relationships between companies established in Brazil and those based abroad were first investigated, with a focus on Brazil and France (ANTAS JR, 2019a; 2019b), and subsequently expanding to include the United States, Germany, and China (ANTAS JR, 2024), which host the world's largest health industrial complexes. As an initial step in this analysis, the industrial products identified by SEADE were matched to their corresponding Harmonized System (HS) classifications, along with the HS codes assigned to their constituent components, here referred to as production inputs.

Once the HS codes had been identified, export and import data were collected from the United Nations COMTRADE database to analyze trade values for each country's industrial sectors and identify its principal trading partners. These data also revealed hierarchical differences among countries in terms of trade values (US$), quantities, and volumes. Their systematization demonstrated that the industrial production of high-value-added sectors is globally fragmented, with transnational corporations coordinating financial networks and the international technical division of labor. Moreover, the industry is characterized by an exceptionally high demand for

[2] The Brazilian Institute for Geography and Statistics.

technological innovation, the intensity of which is closely related to the diversity of industrial sectors and the productive capacity of each country.

Although trade flows of finished products and their components do not, by themselves, fully explain the distribution of health industrial complexes across countries, they nevertheless provide important insights into their spatial organization. This is particularly true of trade in product components, as imports of these goods indicate the productive consumption of intermediate inputs by industries located in the importing countries. Accordingly, the list of importing and exporting countries served as an indicator for selecting the twenty-five largest countries for analysis[3], while recognizing that health economic-industrial complexes may also exist in countries outside this group. A more detailed discussion of this methodological procedure is provided in ANTAS JR (2024).

Another element examined was the presence of transnational corporations in the pharmaceutical and biotechnology sectors, as well as in the medical equipment and devices sector, commonly referred to as the medtech industry. The twenty-five highest-revenue companies in each sector in 2024 were selected, and the locations of their manufacturing facilities were identified. Commercial representative offices were excluded, since the objective was to assess the productive capacity associated with the health economy in the countries where it is most significant, following the same approach adopted in the analysis of production input flows. The dataset was compiled in four stages: (1) identification of the twenty-five highest-revenue companies in 2024 based on data from CompaniesMarketCap and the companies' financial statements; (2) automated searches for the selected companies using OpenStreetMap, considering only sites classified as industrial land use; (3) manual validation of the results, confirming the existence of manufacturing plants through corporate reports or by verifying the presence of large industrial facilities using satellite imagery and Google Street View; and (4) manual completion of the dataset through the inclusion of manufacturing plants identified in corporate reports and scientific publications but absent from the initial search results.

The pharmaceutical and biotechnology sectors, together with the medical equipment and devices sector, account for the largest share of value added, coordinate global production networks, and shape the flow of capital and production, thereby exerting increasing influence over the temporal organization of production on a global scale. This hegemony also affords

[3] Although the selection of twenty-five countries was necessarily arbitrary, the cutoff proved to be empirically robust: the countries ranked below this threshold exhibited substantially lower trade values and volumes, a less diversified industrial base, and fewer trading partners.

these corporations considerable political influence vis-à-vis national governments (ANTAS JR, 2020). Their presence within a given territory further implies the existence of an extensive network of local and regional firms, including both domestic enterprises and foreign companies with a more limited geographic reach.

Accordingly, the number and diversity of the production facilities operated by the selected companies were treated as important indicators of the existence of a health economic-industrial complex (HEIC) within a given country. These facilities provide access to innovation and technological capabilities, while operating through production networks that outsource specific stages of the manufacturing process—often involving lower value-added activities, but in some cases also research and development—to specialized local firms. In the pharmaceutical sector, such firms are commonly known as contract manufacturing organizations (CMOs) or contract development and manufacturing organizations (CDMOs), which specialize in specific stages of the production process, such as product development, manufacturing, or regulatory compliance. Comparable organizational arrangements also exist in the medical technology sector.

The presence of these large corporations points to many other factors that can serve as benchmarks for assessing the existence, scale, and significance of a health economic-industrial complex. Their operations depend on integration into global supply chains, reflecting productive linkages with other countries that host comparable complexes and participation in the international technical division of labor. Collectively, these characteristics indicate the level of productive complexity attained by a country's specialized health industries.

Another key indicator in defining the concept is scientific innovation. As Gadelha et al. (2018, p. 2120) observed, “the unequal distribution of technologies and national innovation bases gives rise to situations of structural dependence in national development patterns, with particularly significant implications for the health sector”.[4] To capture this dimension, patent production, the establishment of technology parks specializing in pharmaceuticals, biotechnology, and medical technologies, and the formation of significant clusters involving firms and public institutions were analyzed. As noted earlier, the inclusion of the term "economic" in the HEIC concept is intended precisely to emphasize the role of scientific and technological innovation in its systemic configuration.

Therefore, the present analysis brings together three fundamental dimensions for characterizing the material basis of health economic-industrial complexes: specialized industrial production in

[4] This and all other non-English citations hereafter have been translated by the authors.

the health sector; the formation of global circuits of capital accumulation led by transnational corporations; and the scientific and technological capacity to generate innovation. Clearly, other factors could certainly be considered in identifying countries that possess HEICs. However, these three dimensions were selected because they capture the core features of the productive capacity of health-related technological goods. Although highly relevant, factors such as national health systems, international trade performance, and corporate finance were not included, as they do not, in themselves, constitute defining characteristics of a country's productive capacity in the health sector and therefore fall beyond the scope of this article.

Lastly, the analysis of the characteristics that distinguish health industrial complexes across countries, made it possible to identify their differences and similarities, patterns of interconnection, and degrees of dependence. Overall, the findings indicate that only a limited number of countries possess robust and comprehensive health economic-industrial complexes. Others, while less developed, nevertheless maintain diversified productive structures of sufficient scale, whereas many remain highly dependent on production located abroad.

Results and discussion

Global distribution of health economic-industrial complexes based on the flow of production inputs

In the current era of globalization, economic practices first adopted by large corporations three or four decades ago have become firmly established and widespread on a global scale, giving rise to increasingly complex productive and technological paradigms. Initially experimental in nature, these practices have since become constitutive of the modus operandi of transnational corporations, reshaping the spatial organization of production and generating new territorial dynamics.

A central expression of these new spatial practices is the emergence of global production networks (HENDERSON et al., 2011), which have become a defining feature of contemporary industrial corporate capitalism. A key insight of this body of research is that corporations increasingly operate simultaneously across multiple territories and as a practice of ubiquity (ANTAS JR, 2020). This development reflects a deepening of the technical-scientific-informational milieu (SANTOS, 1994), whose underlying rationality shapes the strategies of both large corporations and States in the pursuit of productivity gains, fostering a territorially differentiated division of labor characterized by global integration and centralized control.

The expansion of global supply chains across different sectors of the economy has led to the widespread globalization of industrial production[5]. The secondary sector appears to have been the last major sector to undergo large-scale globalization within the international division of labor. In this process, the flows of production inputs—defined here as the components of finished goods—circulate among countries through unequal exchange before being assembled into final goods at manufacturing facilities distributed across multiple territories. This highly structured production model enables corporations to maintain hegemonic control over each industrial sector.

Nevertheless, this process is far from homogeneous, varying according to the technological specificities and the patterns of consumption associated with different products. In the case of health-related industrial production, manufacturing is distinguished by significant particularities, especially with respect to certification requirements, which impose additional constraints on the sector. Even so, it continues to exhibit broad industrial characteristics common to industrial production as a whole.

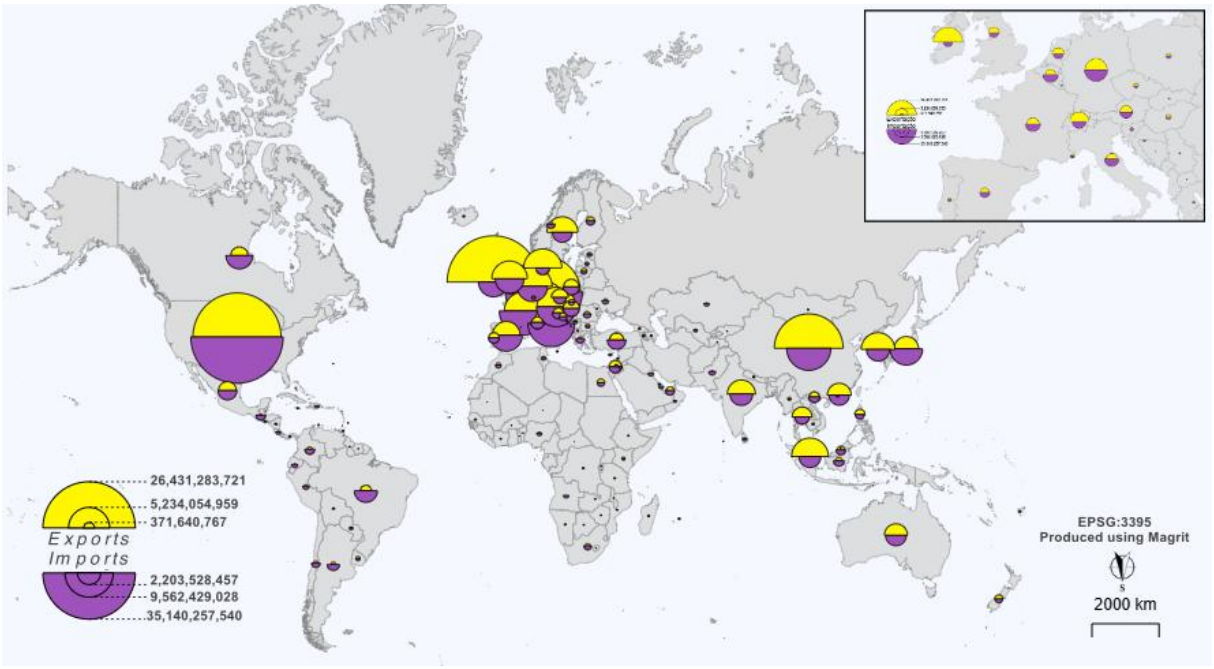
One such characteristic is the integrated organization of the highest-value-added sectors, which are almost invariably controlled by transnational corporations operating through global production networks. Within this framework, exchanges occur both among different firms located within the same territory and among facilities belonging to the same corporation but distributed across different countries. Because many of these corporations exert considerable influence over—if not direct control of—global production networks, they frequently maintain complementary activities across multiple locations, while simultaneously acting as conduits for the global circulation of local and regional production.

The central role of production input flows, which have expanded steadily across several sectors of the health industrial complex since the early 2000s, is therefore readily apparent. Although the existence of a complex is not a prerequisite for this production model to operate, it is precisely within such complexes that these economic practices have been most firmly established. Map 1, which depicts the countries that import and export production inputs for the

[5] It is important to distinguish between the concepts of global production networks and global supply chains as they are used in this article. The former constitute an analytical and structural category for understanding the integration of territories and firms into global capitalism (HENDERSON et al., 2011), whereas the latter represent an operational and managerial category concerned with the efficient management of material and information flows (BALDWIN, 2012). The two are closely interconnected, insofar as the study of global production networks can be refined through the analysis of global supply chains, particularly with respect to the flows of production inputs.

health economic-industrial complex, highlights the principal participants. Notably, the largest importers also tend to be the leading producers of both finished goods and production inputs.

Map 1 – Exports and imports of production inputs for the health economic-industrial complex in 2022



Source: United Nations COMTRADE.

Data organization: Fernandes and Penz

Cartography: Fernandes, using Magrit (CNRS).

Map 1 highlights the central role of the United States and Western Europe in health-related industrial production. China has also emerged as a major exporter of production inputs while simultaneously maintaining substantial import volumes, comparable to those of France, Belgium, Italy, and Switzerland. It is important to note that China's position was markedly different two decades ago: the country imported ten times fewer industrial inputs and exported twenty-two times fewer than it does today (COMTRADE, 2022).

Although this is not the primary focus of the present analysis, it is important to recognize that a health economic-industrial complex is not defined solely by its productive capacity, even though production constitutes the central concern of the political economy of health perspective adopted in this study. From this standpoint, health systems remain a fundamental component of the HEIC. Brazil provides an illustrative example. In 2022, the country imported approximately US$2.2 billion in production inputs—an amount comparable to that of Canada

and Russia, and exceeding the import values recorded by South Korea, India, Singapore, and Australia. These figures indicate a substantial productive capacity.

In Brazil, the importance of domestic health demand is readily apparent. As a middle-income country, Brazil maintains a significant level of production directed primarily toward the domestic market, largely in response to a demand generated by the SUS, although private-sector consumption also plays a significant role. This pattern is reflected in the country's high volume of imported finished goods, in contrast to its relatively modest exports of both production inputs and finished goods. Together, these characteristics reveal the subordinate position of Brazil's health economic-industrial complex within the global economy. The central role of domestic consumption, closely linked to the health system, can likewise be observed in countries such as France, Canada, the United Kingdom, Japan, and, more recently, China—all of which feature prominently in Map 1.

The largest health industrial complexes—notably those of the United States, Germany, and, more recently, China—also rank among the world's leading importers. As demonstrated in Table 1, Brazil did not appear among the ten largest importers, and in 2022, ranked fifteenth. The hegemonic position of these countries stems from multiple factors, among which the strategic importance of production inputs is particularly significant. To a large extent, these imports are undertaken by transnational corporations, enabling them to coordinate and maintain control over industrial sectors operating at the local and regional levels.

Table 1 – International trade in production inputs for the health industrial complex in 2022

Country	Imports (US$ billions)	Country	Exports (US$ billions)
United States	35.1	**Ireland**	26.4
Germany	22.1	**Unted States**	24.0
Belgium	9.6	**Germany**	14.9
France	9.5	**China**	14.6
Italy	8.9	**Switzerland**	10.9
Switzerland	8.1	**Netherlands**	4.7
China	8.0	**Austria**	4.6
Austria	6.5	**Denmark**	4.5
Japan	4.3	**France**	4.4

Spain	4.1	**Singapore**	4.1

Source: United Nations COMTRADE, 2022

Imports of production inputs by countries with well-established complexes are generally concentrated in high-value-added goods that account for a substantial share of the final value of manufactured goods. By contrast, in many peripheral countries, imported pharmaceuticals undergo little more than packaging before commercialization. Core countries, on the other hand, typically import active pharmaceutical ingredients (APIs) and other relatively low-cost inputs used in the manufacture of pharmaceuticals, medical devices, and hospital supplies, which are subsequently transformed through value-adding production processes before being consumed domestically or exported.

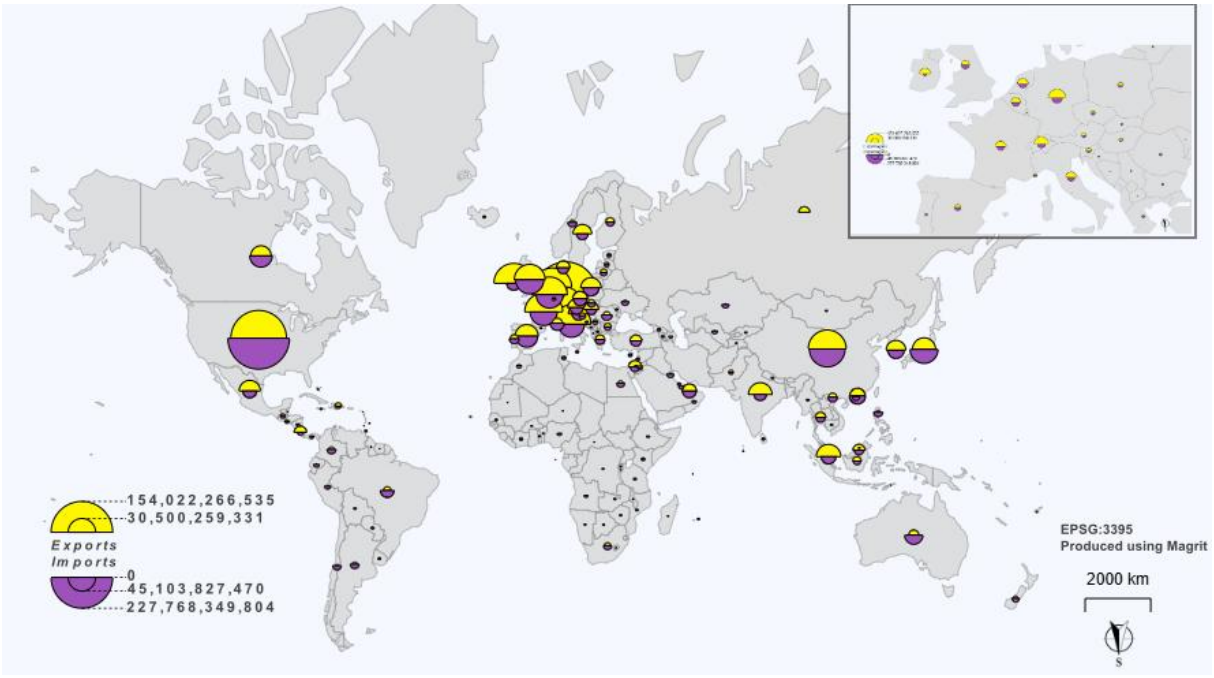
Another important aspect concerns the export of production inputs. Since the COVID-19 pandemic, the remarkable production capacity of China and India in APIs has attracted considerable attention. However, concerns over this issue had already emerged in Europe and the United States by the late 2000s. In France, for example, institutional reports published during this decade warned of the national security risks associated with the decline of domestic low-cost API production (FRANCE, 2005), highlighting the vulnerability created by potential disruptions to global supply chains (CHARPIN et al., 2021), as became evident in 2020.

Another noteworthy finding presented in Table 1 is Ireland's leading position, with US$26 billion in exports, followed closely by the United States (US$24 billion), which is also one of the principal destinations for Irish exports. Ireland has established itself as a major hub within both pharmaceutical and medtech production networks (O'DWYER et al., 2017). Of the US$35 billion in production inputs imported by the United States in 2022, US$13 billion originated in Ireland, followed by Germany and China (US$3 billion each). Despite this substantial manufacturing base, however, Ireland experienced significant challenges during the COVID-19 pandemic, demonstrating that a large-scale production base for both production inputs and finished goods does not, by itself, imply the existence of an autonomous and resilient HEIC capable of fully meeting the health needs of its population.

In light of the foregoing, an analysis of the import and export flows of production inputs provides a fundamental tool for identifying the world's leading countries in health-related industrial production. Foremost among them is the United States, the undisputed leader of the industry, particularly in the highest-value-added sectors. It is followed by Germany and, at some distance, by countries such as China, Switzerland, Belgium, France, and Italy. When trade in finished goods is examined (Map 2), the pattern remains broadly similar, although trade values

are substantially higher. Germany, the United States, and Switzerland each export more than US$100 billion, while France, Italy, Belgium, and China export between US$50 billion and US$80 billion. On the import side, the predominance of the United States is even more pronounced, reaching US$227 billion, whereas the remaining leading countries record import values ranging from US$30 billion to US$80 billion.

Map 2 – Exports and imports of finished goods from the health economic-industrial complex in 2022



Source: United Nations COMTRADE.

Data organization: Fernandes and Penz

Cartography: Fernandes, using Magrit-CNRS.

The presence of health corporations and the logic of global production networks

The previous section examined the productive capacity of countries by considering the consumption of production inputs by all firms operating within each territory, regardless of their size or position within each sector of the health industrial complex. The analysis now turns to another fundamental dimension: the presence of transnational health corporations, particularly in the pharmaceutical and biotechnology sectors and the medical equipment and devices sector, which together account for the highest levels of value added within the health economic-industrial complex. For reference, the twenty-five largest companies in each of these sectors generated combined revenues of approximately US$1.31 trillion in 2024 (COMPANIES MARKET CAP, 2025a, b).

The presence of these corporations in particular cities and regions provides important evidence of the existence of health economic-industrial complexes, since they operate through the logic of corporate networks. Their presence within a given country also indicates the existence of numerous other local or regional firms, which are often linked to these corporations in a variety of ways. As Krätke (2013, p. 1197) observed, these constitute "major pharmaceutical and biotechnology firms' global organisational networks that link cities across the world", enabling the integration of specialized health manufacturing networks with smaller firms specializing in specific stages of the production process, thereby advancing global capital accumulation. This collaborative organizational model has become especially well established in the pharmaceutical industry's CDMOs and CMOs, as well as in equivalent structures within the medtech sector, such as medical device outsourcing (MDO) providers and electronics manufacturing services (EMS) companies.

It is therefore important to understand the topology of the corporate network (SANTOS, 2000, P. 108) that connects different national health complexes. Within each country, specific corporations are embedded in these complexes while simultaneously advancing a transnational logic that secures their hegemony in the highest value-added segments. As Arroyo (2001) argued, by integrating the topology of multiple firms into a single analytical framework, it becomes possible to understand how productive units dispersed across the globe are articulated into a unified functional process, giving rise to networks that encompass multiple places and actors.

Although the stages of the capitalist production process have become increasingly fragmented across geographic space as a result of productive specialization, they are also becoming more closely integrated through the organizational systems of large corporations. Enabled by modernization and the expansion of technical information networks, these corporations are able to coordinate remotely the various nodes and linkages of their production network across the territories in which they operate. The distribution of these nodes is far from random. As Krätke (2013) has argued, there is a network of "global cities in the sphere of manufacturing" associated with pharmaceutical and biotechnology companies and, to varying degrees, with medtech companies as well.

> An interlocking network denotes a specific type of network (see Knoke and Kuklinski, 1982) that consists of a nodal level—the cities—and the sub-nodal level of firms. The cities are connected through actors on the sub-nodal level (the global firms' establishments). They are embedded in networks of

> corporate relationships that enclose transnational intrafirm transactions such as knowledge flows and capital flows. (KRÄTKE, p. 1199, 2013)

Map 3, which compiles approximately six hundred manufacturing plants belonging to the twenty-five largest pharmaceutical companies and the twenty-five largest medtech companies in 2024, reveals a corporate topology that closely aligns with Krätke's (2013) findings while also identifying new production nodes. This pattern reinforces the similarity with the map of input flows, since a substantial share of those flows is generated by the same corporations.

Map 3 – Distribution of the manufacturing plants of the twenty-five largest pharmaceutical companies and the twenty-five largest medtech companies (by revenue in 2024)

Source: Data collected and verified by the authors, based on reports from CompaniesMarketCap, the companies financial reports, OpenStreetMap and Google Street View

Cartography: Fernandes, using QGis.

This corporate topology demonstrates that the countries hosting the manufacturing plants of the corporations analyzed coincide with those exhibiting the largest flows of productive inputs, corroborating the existence of highly dynamic health economic-industrial complexes on a

global scale. These complexes articulate local, national—and, in some cases, public enterprises—with the global and multinational corporations that structure the network.

In addition to these major corporations, the presence of CMOs and CDMOs is particularly noteworthy, and although some may operate on a global scale, most function primarily at the regional and local levels. Their presence demonstrates how transnational corporations structure their corporate networks by bringing together a much broader array of specialized productive firms that supply inputs to global market leaders. In many cases, CDMOs acquire manufacturing plants from large corporations, thereby guaranteeing supply to the original company while retaining the freedom to sell surplus production to other firms in the sector.

Map 4 shows the global distribution of these companies based on data from regulatory agencies and employers' associations. These figures should be understood as an expression of the corporate logic of productive fragmentation through specialization and of integration among firms through capitalist cooperation. In many countries, the terms CMO and CDMO are either relatively new or are not yet widely used, which may lead to an underestimation of their actual presence. Moreover, many globally operating CDMOs enter national markets as organizational systems without establishing manufacturing facilities, instead contracting the local production of pharmaceuticals or medical devices. As a result, the figures compiled for Map 4 likely underestimate the true extent of these networks.

Map 4 – Number of CDMO/CMO manufacturing plants by country in 2025

Source: Data collected and verified by Antas Jr. based on reports from employers' associations specializing in the pharmaceutical sector, as well as the companies' financial reports.

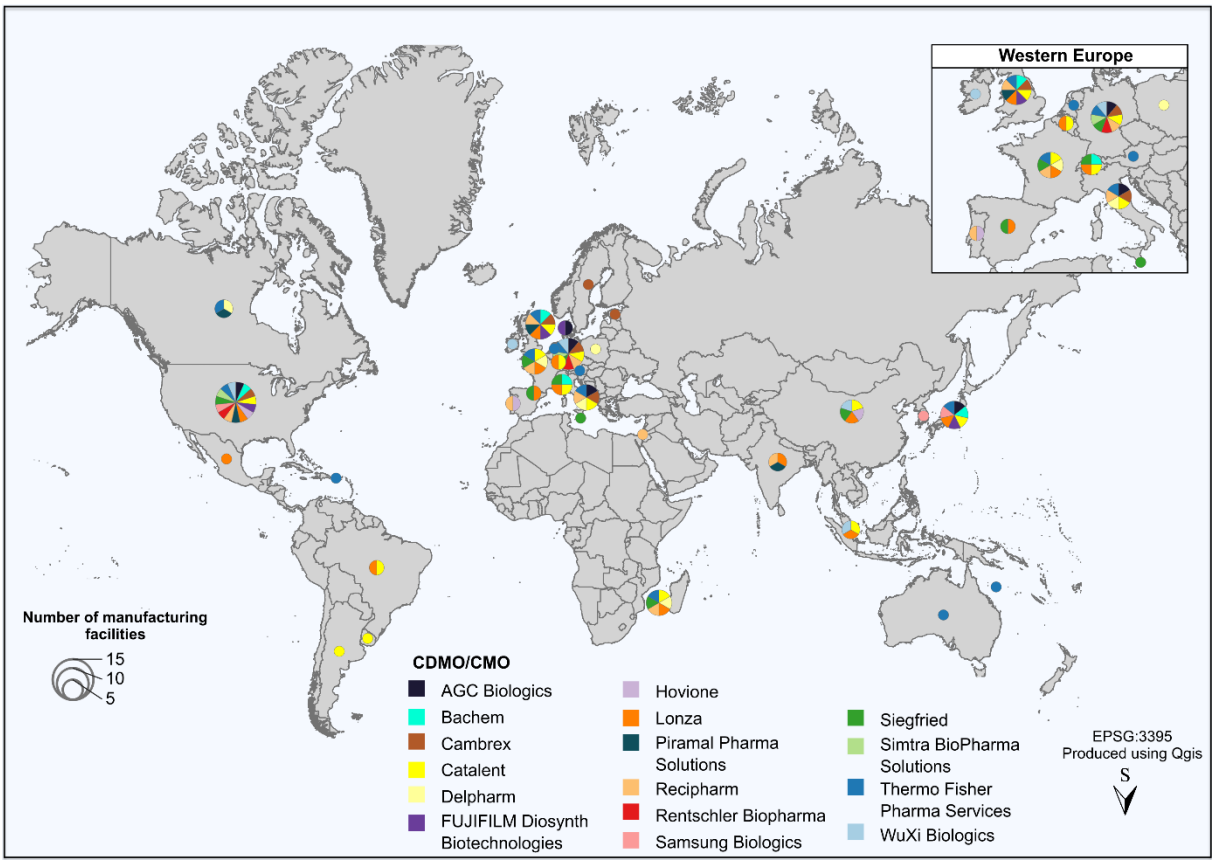
Cartography: Fernandes and Penz, using QGis.

Thus, beyond the figures presented, it is important to recognize that there is a much larger contingent of local and regional firms in each country, particularly in those with strong potential to host health industrial complexes. This observation is further reinforced by the overlap among the different maps analyzed here.

It should be emphasized that globally operating CMOs/CDMOs have emerged only within the past two decades. Until the late 1990s, this form of productive specialization was viewed with scepticism, as the value of a health corporation was thought to depend largely on its ability to internalize every stage of the production process, thereby ensuring product quality and reliability. By the mid-2000s, however, it had become evident that the global expansion of major pharmaceutical companies depended on CMOs/CDMOs, not only for the supply of specialized inputs but also to facilitate compliance with certification requirements of national regulatory agencies. Their strategic importance and structuring role within the corporate topology of the pharmaceutical and medtech sectors were soon recognized, driving their global expansion, particularly across established and emerging markets. Map 5 illustrates the

international presence of these globally operating companies by identifying the countries in which they maintain operations.

Map 5 – Number of manufacturing plants operated by global CMO/CDMO companies by country, 2025



Source: Data collected and verified by Antas Jr. based on reports from employers' associations specializing in the pharmaceutical sector, regulatory agencies, and the companies' financial reports.

Cartography: Fernandes and Penz, using QGis.

The distribution of these companies, operating at all scales, therefore extends beyond mere illustrative examples, as it reflects the corporate logic underlying the sectors analyzed and their capacity to establish hegemony over a much broader set of nationally based firms, operating within their respective territories, thereby reinforcing the evidence of a significant productive apparatus linked to the health sector.

Technological innovation in health economic-industrial complexes: technology parks, clusters, and patents

Technological and scientific innovation constitutes one of the defining features of the health economic-industrial complex, as emphasized by Gadelha and his research team. Indeed, this

aspect was one of the main justifications for reformulating the original concept of the "health industrial complex".

This characteristic is shared by all health economic-industrial complexes worldwide, since they encompass industrial sectors dedicated to the production of high value-added goods whose competitive advantage rests on technological and scientific innovation. This capacity is often associated with the substantial investments in research and development (R&D) made by large corporations, as is evidenced by their financial reports. Public investment, however, is equally decisive, whether through state-owned enterprises or the creation of structural conditions that foster business innovation. Key public policy instruments include the establishment of technology parks that host startups, small and medium-sized enterprises (and, in some cases, large corporations), direct public investment, tax incentives, subsidized credit, and collaboration with public universities.

Technology parks are therefore hybrid ventures involving both the State and private capital. They frequently emerge either through initiatives by transnational corporations seeking to expand into new territories or through government policies aimed at promoting innovation. Technology parks dedicated to the development of pharmaceutical, biotechnological, and medical technologies are typically located in city-regions that already function as clusters in these sectors. They should not be conflated with the clusters themselves; rather, they reinforce existing specialization by increasing local productive density. In other cases, explicit government support for the establishment of technology parks serves as a strategy for technological and industrial transformation aimed at fostering the development of clusters. Prominent examples include the Greater Pearl River Bay Area (China) (PECK, 2021; PECK et al., 2025; SPARKE et al., 2023), Bangalore (India) (PANDEY; DESAI, 2017), and Cork (Ireland) (O'DWYER et al., 2017).

Indeed, these are primarily globalized urban regions that concentrate the nodes of the corporate network associated with the health economic-industrial complex. More specifically, they are city-regions that perform specialized functions within global production chains, either through manufacturing activities located in metropolitan industrial zones or through the provision of specialized services that coordinate those chains (KRÄTKE, 2013). Table 2 presents the world's leading clusters in the sectors analyzed.

Table 2 - Ten largest clusters by type worldwide

	Pharmaceutical Clusters	**Biotechnology Clusters**	**Medical Technology Clusters**

1.	Boston-Cambridge (US)	Boston-Cambridge (US)	Tokyo-Yokohama (JP)
2.	San Jose-San Francisco (US)	Raleigh (US)	Seoul (KR)
3.	Shanghai-Suzhou (CN)	Copenhagen (DK)	San Jose-San Francisco (US)
4.	New York City (US)	Oxford (GB)	Los Angeles (US)
5.	San Diego (US)	Washington, Baltimore (US)	Eindhoven (ND)
6.	Philadelphia (US)	Philadelphia (US)	Boston-Cambridge (US)
7.	Los Angeles (US)	Cambridge (GB)	Minneapolis (US)
8.	Washington, Baltimore (US)	New York City (US)	Shanghai-Suzhou (CN)
9.	Tel Aviv-Jerusalém (IL)	Basel (CH/DE/FR)	Osaka-Kobe-Kyoto (JP)
10.	Basel (CH/DE/FR)	Wuxi (CN)	Cincinnati (US)

Source: World Intellectual Property Organization (WIPO), 2024

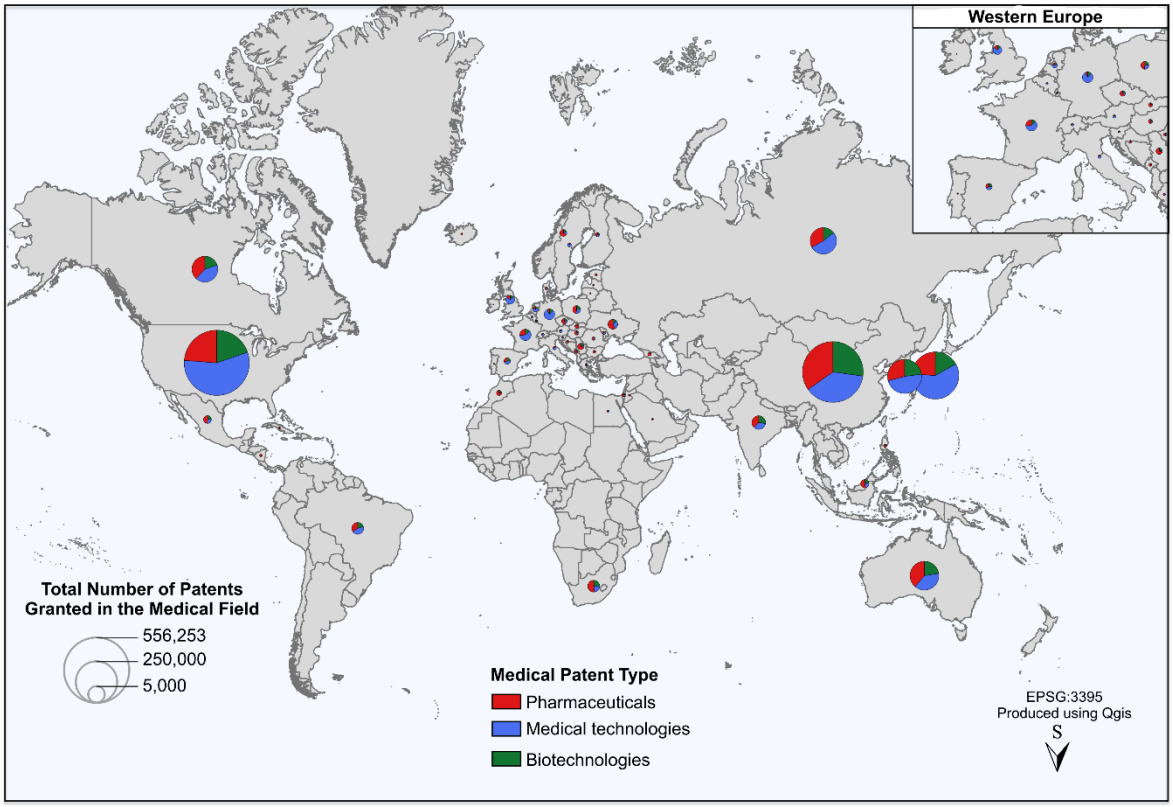
In the United States, the most prominent clusters include Los Angeles, San Jose–San Francisco, New York, Boston, and five other major clusters. In China, they include the Greater Pearl River Delta Bay Area, encompassing Shenzhen, Hong Kong, Guangzhou, and Macau (PECK, 2021), as well as the Wuxi–Shanghai–Suzhou cluster. In the United Kingdom, the leading clusters are Oxford and Cambridge, while in Japan they include Tokyo–Yokohama and Osaka–Kobe–Kyoto, to cite only some of the principal hubs within this corporate topology. In Brazil, this pattern is evident in the metropolitan regions of Rio de Janeiro, Belo Horizonte, and Florianópolis (as well as in the intermediate cities within their spheres of influence). São Paulo is the only Brazilian metropolis to appear in international rankings; in the WIPO rankings, it is positioned between fifteenth and thirty-fifth place in the sectors presented in Table 1.

In addition to these biopharmaceutical centers integrated into global production networks, Sparke, Malmberg, and Malpass (2023) also highlight major manufacturing centers in these sectors, including Cape Town (South Africa) and Singapore. O'Dwyer et al. (2017) emphasized the role of Dublin, while Krätke (2013) identified Mexico City, Toronto, Sydney, and São Paulo as key nodes within this corporate network of pharmaceutical and biotechnology companies.

The production of innovation in these major centers is fundamental to the consolidation of health economic-industrial complexes. Countries offering the most favorable conditions for

technological and scientific innovation—whether through government incentives or direct corporate investment—are often those that host the largest and most diversified health economic-industrial complexes. Maps 6 and 7, which depict patents registered in the sectors examined, provide further evidence of this pattern. They reinforce the identification of the countries that host these complexes, while also showing that researchers from European countries frequently register patents in countries outside Europe, particularly in Brazil, South Africa, Australia, Russia, India, and Canada.

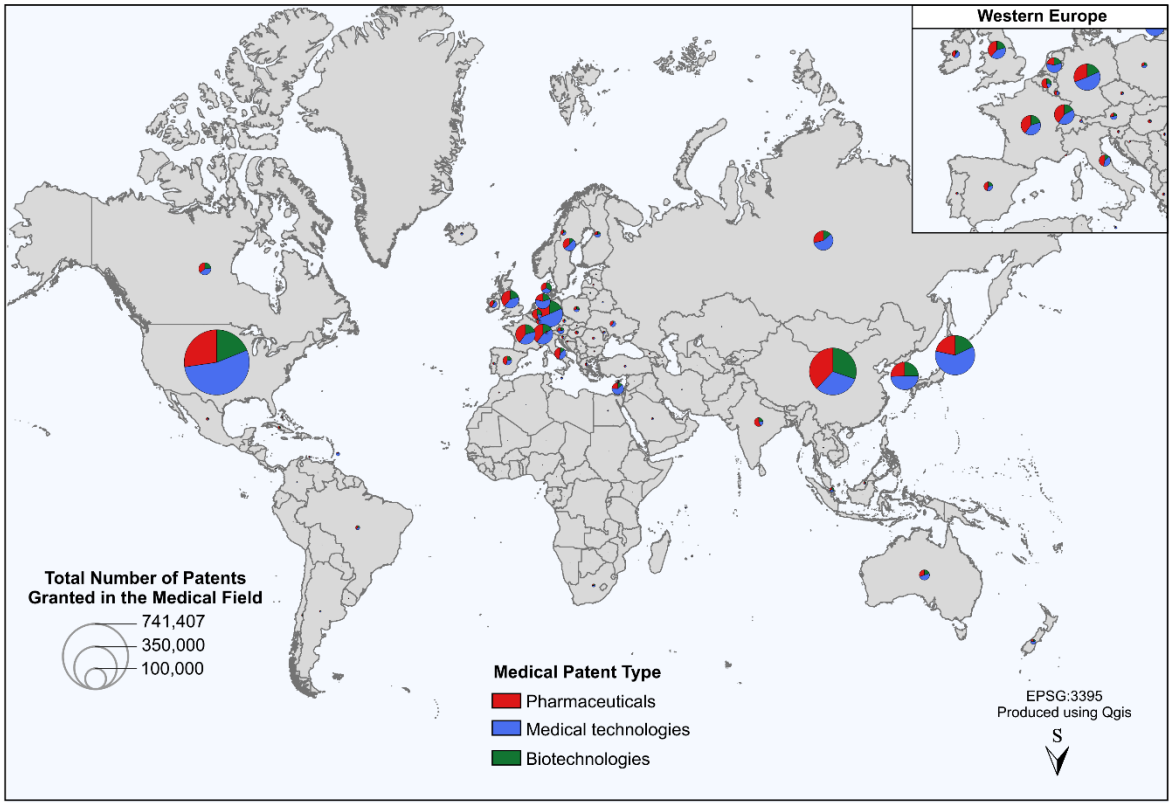
Map 6 – Total number of patents granted by each country's patent office, 2000–2023



Source: WIPO, 2024.

Cartography: Fernandes and Perez, using QGis.

Map 7 - Total number of patents granted by applicants' country of origin (2000-2023)



Source: WIPO, 2024.

Cartography: Fernandes and Perez, using QGis.

A comparison of Maps 6 and 7, together with an analysis of the annual WIPO (2025) reports on patent registrations, reveals that patents originating in Europe, in countries such as France, Germany, the United Kingdom, and Denmark, have increasingly been registered in emerging economies, attracted largely by local government support programs and support programs (KRÄTKE, 2013; O'DWYER; NOLAN; FISHER, 2017; PANDEY; DESAI, 2017; PECK et al., 2025). This trend provides compelling evidence of the growing internationalization of innovation under the logic of transnational corporate networks.

Health industrial complexes or health spatial production circuits?

There is no reason to establish a rigid opposition between these categories, since the former are national in scope, whereas the latter are structured through the integration of scales, from the local to the global. They therefore represent distinct yet complementary dimensions of the contemporary world-system. The apparent dichotomy implied by this distinction nevertheless

warrants consideration, since these realities are linked by very subtle connections, and in many cases, exhibit no readily apparent differences in the landscape.

On the one hand, the health economic-industrial complex refers simultaneously to the specialized industrial base and to the broader health system, both public and private. It includes credit policies and incentives for the different productive sectors, the consumer market, national health policies, and national innovation systems, all of which are shaped by the central role of the State. In essence, it constitutes the political economy of health within each socio-spatial formation.

The spatial production circuits of health, as explained by Santos (1988), originated within regional economies but, following the end of the Fordist era, were rapidly incorporated into transnational production dynamics coordinated by private actors—albeit often fostered by the State—with the aim of expanding capital accumulation on a global scale. The articulation of global production networks with supply chains, mediated by a globalized financial system, further reinforces the transnational character of these circuits. Consequently, they tend to reinforce the prevailing logic through the concentration of infrastructure and the intensified exploitation of available markets.

The health economic-industrial complex, by contrast, should be understood as a strategic resource of the State. By providing health services to the population, it helps ensure the stability of the socio-spatial formation while also serving as a geopolitical asset. Consequently, countries whose health economic-industrial complex is weak, dependent, or even nonexistent often mobilize State resources to strengthen or establish it. From the standpoint of capital, however, these efforts simultaneously create new opportunities for the expansion of the spatial production circuits of health into new territories, thereby extending the geographical reach of capital accumulation. Although this relationship may appear paradoxical, the two processes are mutually reinforcing. Over the past two decades, the production circuits have expanded geographically into countries where their presence had previously been fragmented and residual.

In these regions, which until two or three decades ago possessed only small industrial facilities geared toward basic consumption and characterized by low technological sophistication and limited scientific intensity, productive capacity has expanded rapidly. Nevertheless, even where a health economic-industrial complex has begun to take shape, it remains incomplete and highly dependent on transnational corporations. Countries with more mature, diversified industrial systems, by contrast, display a contradictory trajectory. While they relocate the production of lower-cost inputs to emerging economies, more recently, they have increasingly transferred the

manufacture of higher value-added inputs, including segments of technologically and scientifically innovative activities, to these same locations (ANTAS JR., 2020; 2024).

At the same time, countries with the most consolidated health economic-industrial complexes seek to attract and retain the R&D investments of large corporations through substantial State support as an incentive. This strategy often provides access to research infrastructure and highly qualified personnel at public universities (including publicly funded private institutions), public applied research institutions, as well as guarantees that their national health systems will function as guaranteed lead markets for the resulting innovations.

Nevertheless, recent shifts in the international political-economic order, intensified by the tariffs introduced during the Trump administration, have renewed debates over the need to restore national control over the productive base of the health industry. While these concerns became particularly salient during the COVID-19 pandemic, they had already been expressed in earlier strategic documents, such as the report *La place des biotechnologies en France et en Europe* (FRANCE, 2005), which warned of the loss of sovereignty over the production of health-related inputs as a significant risk to national security.

Even so, the flow of inputs within the health industry continues to intensify, reflecting the underlying logic that drives the organization and geographical expansion of the spatial production circuits of health. This tendency is evident in the rapid growth of global production networks and the increasing sophistication of logistics systems specialized in health. Against this backdrop, an important question emerges: is it feasible to reestablish a political economy of health organized primarily within the boundaries of individual socio-spatial formations, as suggested by recent policy initiatives, particularly in the United States and Europe?

Scientific innovation constitutes the driving force of this techno-scientific system devoted to human care and healing. Emerging diseases require new scientific discoveries, while existing diseases, through their continuous evolution, demand ongoing advances in applied research and industrial production. The twenty-first century has also witnessed pandemics that have posed unprecedented challenges, many of which were overcome within remarkably short timeframes despite the inherent complexity of the innovation process. At the same time, technological innovation and scientific knowledge have become increasingly globalized, and the transformation of knowledge into industrial processes has reached an unprecedented degree of integration across multiple spatial scales.

Thus, while geopolitical and national security interests lead States to strengthen their health economic-industrial complexes by expanding control over productive processes within their territories, the logic governing the spatial production circuits of health promotes an increasing

fragmentation of production, extending even to disruptive innovations. This dynamic is expressed in the dispersion of productive activities across an ever-growing number of cities and countries, ensuring competitive advantages, greater access to resources through subsidies, public investments, and strategic partnerships, as well as reduced vulnerability to shifts in State policies. Not surprisingly, even the United States, historically a strong advocate of economic nonintervention, has experienced growing tensions and uncertainties, revealing the complex articulation among the state, capital, and science in the field of global health.

Final remarks

Drawing on an analysis of production volumes, the flows of finished goods and production inputs, the global distribution of industrial plants operated by major corporations, and each country's capacity to foster innovation, it has been possible to develop an initial, albeit provisional distinction among hegemonic, complementary, and incomplete health economic-industrial complexes.

The first group comprises the United States and several European countries—notably Germany, Switzerland, the United Kingdom, and France—as well as Japan and China. These countries stand out across virtually all of the analyses presented. In China's case, its inclusion in this group is more recent, reflecting its rapid growth in production and innovation, consistent with its broader trajectory of industrial expansion across a wide range of manufacturing sectors.

The second group, classified as complementary, includes countries such as Brazil, Australia, India, South Korea, Mexico, Singapore, and Ireland, among others. These countries possess significant productive capacity, either oriented toward meeting domestic demand, as in the cases of Brazil, Australia, and Mexico, or toward supplying inputs and products to hegemonic complexes, as is the case for Ireland and India. Even so, in all cases these countries serve their domestic markets while also exporting production inputs to the hegemonic complexes and finished goods on a broad scale.

The incomplete complexes, in turn, generally correspond to countries whose productive expansion has been more recent and characterized by the strong presence of transnational corporations alongside a still-limited domestic industrial base. Historically, these economies have relied heavily on imports and have maintained relatively low levels of domestic production capacity. Nevertheless, they warrant particular attention because they occupy strategic positions

in the expansion of the spatial production circuits of health and are closely aligned with national development policies. Notable examples include South Africa and the Philippines.

It should be emphasized that this study did not seek to establish a definitive conceptualization or an exhaustive classification of all countries possessing a health economic-industrial complex. Such an undertaking would require an integrated assessment of specialized productive capacity, the configuration of national health systems, the respective roles of the State and private capital in the provision of health services, and the degree of the population's access to these systems, among other factors. These considerations extend beyond the scope of the present study, which has focused on identifying specialized productive capacity in the health sector and its level of innovation. Nevertheless, they point to promising avenues for future research aimed at integrating these dimensions into a more comprehensive analytical framework.

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