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NANOTECHNOLOGY AND COVID: TECHNICAL SOLUTIONS IN THE HUNT FOR INEQUALITY

Edgar Záyago Lau, Sein León Silva, and Roberto Soto Vázquez

Abstract

This chapter argues that in the face of the worst economic and health crisis caused by Covid-19, the world's nations have opted for technical solutions to solve the pandemic problem. In doing so, they have subordinated anti-Covid technological development to the laws of capitalist accumulation. Consequently, control of the vaccine production chain has remained in transnational companies located in the most developed countries. We use various analysis methods to advance our argument, including collecting scientific publications, patents, vaccine production, and application. The real success is at the hand of the winners of this pandemic: big pharma.

Keywords: Nanotechnology, pharma, Covid

Introduction

This chapter advances an analysis based on quantitative techniques to show the inequality in the chain production of nano enabled vaccines to treat Covid-19. This inequity is illustrated in the technical and social benefits that developed countries ensure to the detriment of developing countries. Practically, scientific publications, patents, vaccines, and the profits derived from their sales are monopolized among pharmaceutical transnationals. The principle of justice and well-being is subsumed by the interest of profit, even in the most severe health crisis of the last 100 years. The first section explores the contrasting positions on technological progress and its role in solving social problems. In the next section, we explain the potential of nanotechnology-based Covid-19 vaccines. Later we illustrate the different stages of development of these vaccines and the leading role of transnational companies. After that, we highlight some points for reflection in the conclusions section.

1. Technology as a solution for social problems

Beginning in the last century, the accelerated social division of labor made possible the establishment of an "*epistemological hegemony*" in academia, subordinated to the advance of capitalism, in which reality is interpreted or explained without analyzing the historical powers and interests maintaining the *status quo*.

On the one hand, we have the analytical assessment of reality based on the segmentation and overestimation of the rationality of individual agents. In this framework, the partial analysis of social reality is advanced by undervaluing the economic trends and social struggles that determine history. From the imposition of this cognitive matrix, the order and perspective of time and space are reduced to solving specific problems derived from specific areas or disciplines: business administration, industrial engineering, financial economics, marketing, human resources, international business, etc. In aggregate, it is argued that individual competitiveness is a sine qua non-condition to join this hyper-specialized, globalized, interconnected world. Consequently, higher education systems become training spaces for highly trained "technicians" to join the capital appreciation process and serve the dominant groups. These pictures are little or not relevant to become agents of transformation or social emancipation.

In contrast, we have the objective analysis of historical and social development that focuses on studying the economic and political contradictions of the productive systems at a given moment (Marx, 1867). Today, the case takes us to understand that capitalism imposes technical relations (technological development) from the dominant social relations of production (Rubin, 2019). In this context, the ongoing competition inherent in the market economy and the insatiable search for the profit of the producing entities makes technology development an essential aspect of the economic system at all levels. Technology becomes a tool that incubates competitive advantages and allows conquering markets, regardless of whether this logic brings contradictions in the system. In the end, what determines how, when, and why a new machine is introduced into a productive system are the laws of accumulation (Marx, 1867), and not the disposition or the goodwill of the owner of the technology.

Orthodox intellectuals, who defend the subjective conception, unfold concepts that refer to the role of technology in the development process from a natural or evolutionary order (Freeman, 1987; Pérez, 2003). An important setback in these analyzes is that they equate technical relations (technological development) with social relations (between people), and never assume the importance of such a distinction to study the impact of technologies on the labor process (Katz, 1996). Likewise, subjective analysis, even with incorporating the historical axis from the evolutionary or neo-Schumpeterian paradigm, does not focus the research on the social implications of capitalist technological development: employment/unemployment relations, consequences of patents and monopolies, subordination of technological trajectories, heterogeneity, socioeconomic between nations and sectors, and many other issues.

Many scientific and technological areas fall prey to this thinking, and nanotechnology-based vaccines for Covid-19 are no exception. This chapter shows that the solution should not rely exclusively upon the technical. The answer depends on modifying the socio-economic structures that assign technological benefits *vis-à-vis* the advance of profits.

2. Nanotechnology and nanomedicine

Nanotechnology is an interdisciplinary field of science that includes the design of components, materials, devices, and systems at the nanoscale (1-100 nm) (Patel, Patel, & Bhatia, 2021). On this scale, materials present novel properties not observed on larger scales. This novel feature has allowed nanotechnology to be applied in a wide array of sectors such as agriculture, environment, energy, aerospace, chemicals, materials science, and medicine (Nasrollahzadeh *et al.*, 2019). The application of nanotechnology in medicine is called nanomedicine. This new discipline encompasses the use of nanomaterials to diagnose, monitor, prevent and treat diseases at the molecular level (Abdel-Mageed, AbuelEzz, Radwan, & Mohamed, 2021). The main areas of application of nanomedicine are i) drug delivery, ii) drugs and therapy, iii) in vivo imaging, iv) medical biosensors, and v) biomaterials (Wagner, Hüsing, & Bock, 2008).

In drug delivery, nanomedicine has contributed to the development of nanostructures that transport drug molecules to specific parts of the human body. Some nanostructures are widely used for this purpose, such as polymeric nanoparticles, superparamagnetic nanoparticles, quantum dots, dendrimers, and lipid solid nanoparticles (Chamundeeswari, Jeslin, & Verma, 2019). Due to their size, these nanostructures can more easily cross biological and physiological barriers, which improves drug delivery efficiency. Likewise, by manipulating their surface properties, nano carriers can be explicitly targeted to diseased organs and tissues, which reduces the side effects caused by the spread of drugs in healthy organs and tissues. The latter is relevant in developing new cancer treatments since conventional chemotherapies lack selectivity towards cancer cells and cause adverse side effects that decrease patients' quality of life (Chidambaram, Manavalan, & Kathiresan, 2011).

In drugs and therapy, the use of nanomaterials has made it possible to improve or develop new treatments. For example, nanoparticles have become helpful in magnetic hyperthermia therapy (Lemine, 2019) and photodynamic therapy (Kim, Jo, & Na, 2020) to fight tumors. Nanomedicine has also made contributions in two critical areas of diagnostics: in vivo imaging and medical biosensors. In vivo imaging is a diagnostic tool that consists of obtaining images of the human body's interior through magnetic resonance imaging, computed tomography, and positron emission tomography techniques. The use of nanoparticles as contrast agents significantly improves the images obtained with these techniques to detect cancerous tumors early (Kalra *et al.*, 2021). Some nanoparticles that have been used as contrast agents are iron oxide nanoparticles, gold nanoparticles, and quantum dots (Thirugnanasambandan, 2021).

Regarding medical biosensors, these devices take part in the diagnosis for the analysis of in vitro samples. Incorporating nanostructured components in the biosensors has increased the performance and sensitivity of these devices, allowing fast and accurate diagnoses with microscopic models (Huang, Zhu, & Kianfar, 2021). Nanostructured biosensors have been built to detect glucose, cholesterol, Escherichia coli, influenza virus, human papillomavirus, dopamine, and glutamic acid (Kumar, Ahlawat, Kumar, & Dilbaghi, 2015).

Attention has focused on developing highly biocompatible nanomaterials with bactericidal and antiviral properties to make them suitable for medical applications. Two outstanding examples of this type of material are nanostructured hydroxyapatite and silver nanoparticles. Due to its high biocompatibility, Nanostructured hydroxyapatite has been used to manufacture implants (Roy, Bandyopadhyay, & Bose, 2011) and tissue engineering (Zhou & Lee, 2011). Silver nanoparticles have bactericidal properties and have been used to manufacture medical instruments, wound dressings, and bone cement to fix orthopedic implants (Davidovits, 2019).

We overviewed the scientific publications on nanomedicine that have been published in the period 2000-2020. The search for publications was carried out in the Web of Science using a methodology applied in previous works on nanomedicine (Invernizzi *et al*., 2015; Wagner *et al*., 2008). This research showed that in the last two decades, 181,437 articles on nanomedicine had been published worldwide. Figure 1 shows the number of publications per year. The number of publications has increased steadily throughout the period, which indicates that nanomedicine is a growing sector. Chong and Hong (2020) reported that international patent applications on nanomedicine had increased significantly since 2000. When it comes to the nanomedicine market, it has expanded and will continue to do so. In 2009, the global nanomedicine market size was approximately $ 53 billion. In 2017 it was $ 134.4 billion and was projected to reach 293.1 billion dollars by the end of 2021 (Gadekar *et al*., 2021).

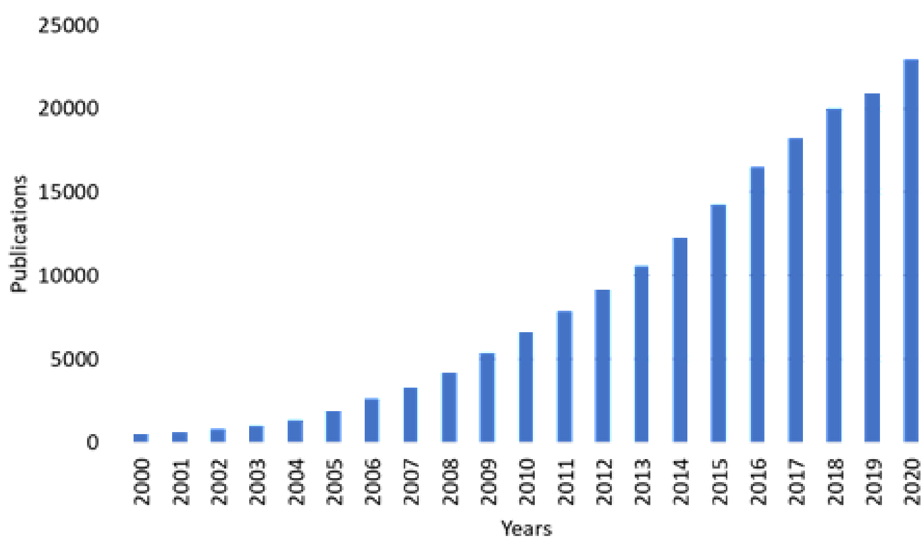

Figure 1. Scientific production on nanomedicine worldwide. Publications per year

Source: *Own elaboration with information from Web of Science (consultation date: August 10, 2021).*

Figure 2-A shows the ten countries with the highest number of publications. China, the United States, and India lead scientific production on nanomedicine. These countries have national nanotechnology initiatives to direct and finance research and development activities (Bhattacharya, Shilpa, & Bhati, 2012; Merzbacher, 2020). Figure 2-B shows the distribution of publications by area. It is observed that the areas with the highest number of publications are drug administration (59% of the total), in vivo imaging (15%), and medical biosensors (11%).

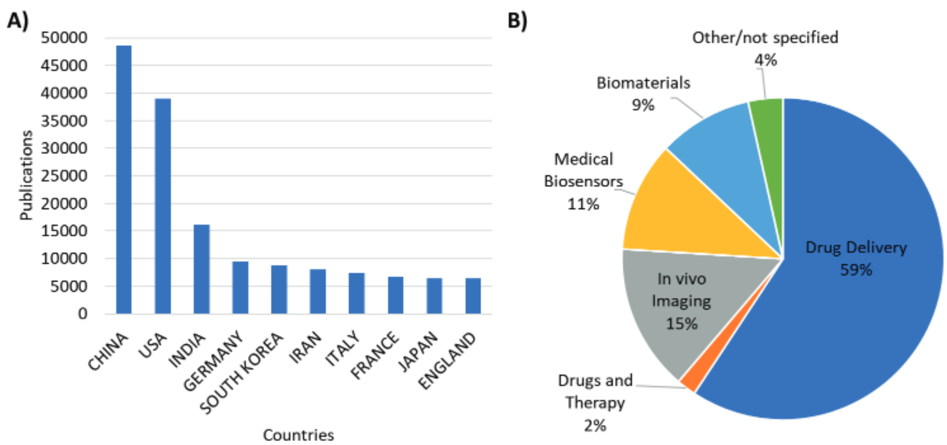

Figure 2. A) Countries with the greatest scientific production on nanomedicine. B) Distribution by areas of the world production of nanomedicine.

Source: *Own elaboration with information from Web of Science (consultation date: August 10, 2021).*

In the current context of the COVID-19 pandemic, nanomedicine has made contributions to combat this disease. In our bibliometric analysis, we also explored the publications on nanomedicine focused on COVID-19. To do this, we incorporated into the search strategy keywords about COVID-19 and SARS-CoV-2 that have been used in previous work (Hossain, 2020). We tracked the articles that have been published from 2019 (the year the disease appeared) to the present (August 2021) and found a total of 438. Figure 2-A shows the ten countries with the highest number of publications. China, the United States, and India lead scientific production on nanomedicine. These countries have national nanotechnology initiatives to direct and finance research and development activities (Bhattacharya, Shilpa, & Bhati, 2012; Merzbacher, 2020). Figure 2-B shows the distribution of publications by area. The areas with the highest number of publications are drug administration (59% of the total), in vivo imaging (15%), and medical biosensors (11%). To identify the topics covered in these publications, we build a word cloud with the keywords that appear most frequently. Figure 3 shows this word cloud. Nanomedical research for COVID-19 has focused on designing biosensors for diagnosing the disease and the development of vaccines.

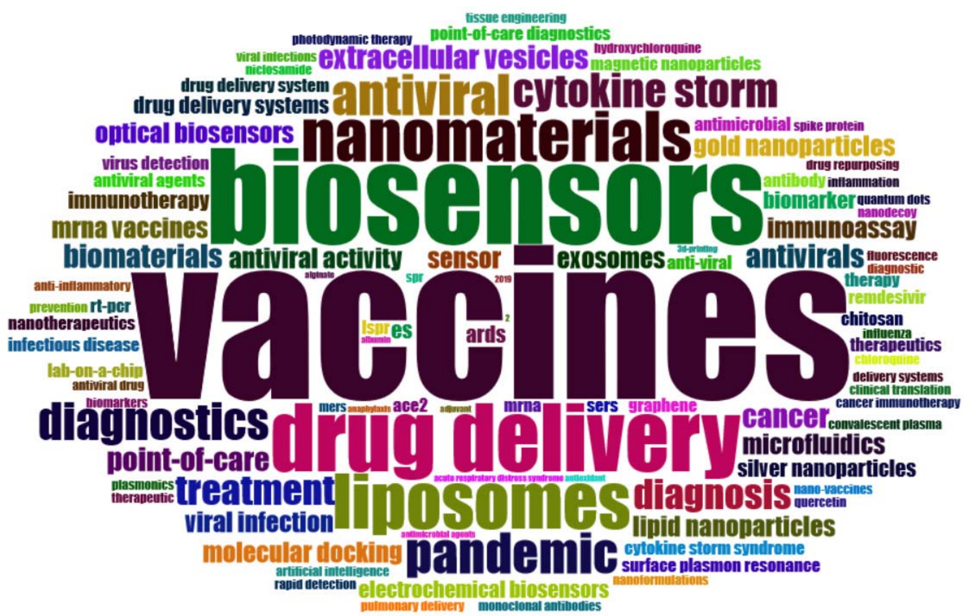

Figure 3. Most frequent keywords in the publications of nanomedicine applied to COVID-19. The size of the words is proportional to the number of times they appear in the posts. To improve visibility, obvious words such as COVID-19, SARS-CoV-2, coronavirus, nanotechnology, and nanomedicine were excluded. Figure generated with R's Bibliometrix package with information from Web of Science (date of consultation: August 10, 2021).

3. Nano-based vaccines and inequality

Due to the current COVID-19 pandemic, nanotech-based vaccines have been accelerated, reformulating existing drugs, improving their delivery, and achieving more effectiveness (Vargason *et al.*, 2021). Additionally, nanoparticles can act as transport vehicles for molecules, capable of crossing natural barriers, limiting the interaction with other elements, reducing toxicity, decreasing adverse effects in the body, and supplying drugs specifically to different tissues (Din *et al.*, 2017). In the vaccines sector, nanotechnology has influenced principally in three different purposes:

1) Increase of immunogenicity as an auxiliary stimulant to generate an immune response.
2) Increase the stability of antigens, protecting them from premature degradation caused by proteolytic enzymes.
3) Targeted delivery systems to facilitate antigen uptake (Talebian & Conde, 2020).

Usually, vaccines work by inserting a sample of the virus into the immune system, but without causing the disease. This can be achieved by including critical components of the virus such as the envelope, spike, or membrane protein. Then, the immune system identifies the atypical protein and attacks the virus, creating antibodies to protect the subject against the actual virus if it shows up (Centers for Disease Control and Prevention (a); National Audit Office, 2021). For Covid-19 vaccines, it is a similar case, though, since to date, there are three different formulations (National Institute of Allergy and Infectious Diseases; World Health Organization; U.S. Dept. of Health and Human Services, 2021):

Protein subunit: This type of Covid-19 vaccines includes parts of the virus (S proteins) that stimulates the immune system. Once the immune system recognizes S proteins, it creates antibodies and white blood cells to fight the virus. Novavax works as a protein subunit COVID-19 vaccine (Centers for Disease Control and Prevention (b), 2021).

Vector vaccine: It contains inside a modified virus envelope, material from the virus COVID-19 (viral vector). Once the viral vector is in our cells, the genetic material instructs the cells to make copies of the protein S, in response the immune system creates defense antibodies and white blood cells that are unique to attack COVID-19. Viral vector vaccines cannot make you infected with COVID-19 virus or the viral vector virus. Johnson & Johnson's Janssen, AstraZeneca and the University of Oxford are vector vaccines against COVID-19 (Centers for Disease Control and Prevention (b), 2021).

Messenger RNA (mRNA) vaccines: This novel method uses genetically modified mRNA, which instructs our cells to create protein S. Once our immune system cells copy the protein S, they destroy the genetic material in the vaccine. It recognizes that this protein should not be present creating T lymphocytes and B lymphocytes that will attack if the actual Covid-19 virus appears. Pfizer-BioNTech and Moderna COVID-19 vaccines use mRNA method. (National Center for Immunization and Respiratory Diseases (NCIRD), Division of Viral Diseases, 2021). The mRNA encapsulation technique is a novel method that possesses high effectiveness. Nevertheless, the instability of mRNA molecules requires high precision, for which nanoparticles have been used to embed in lipids to achieve its stability (Centers for Disease Control and Prevention (c); Mayo Clinic, 2021).

However, all this cutting-edge research requires extensive funding and specialized personal capable of transferring the nanotechnological theoretical knowledge into concrete applications and devices as vaccines. Therefore, according to the Global Health Centre of the Graduate Institute Geneva (2021), the United States and Germany are the largest investors in vaccine Research and Development (R&D), followed by China, Great Britain, and European Union (Figure 4). The 90.7% of the 6.6 billion dollar investment in R&D comes from the public sector.

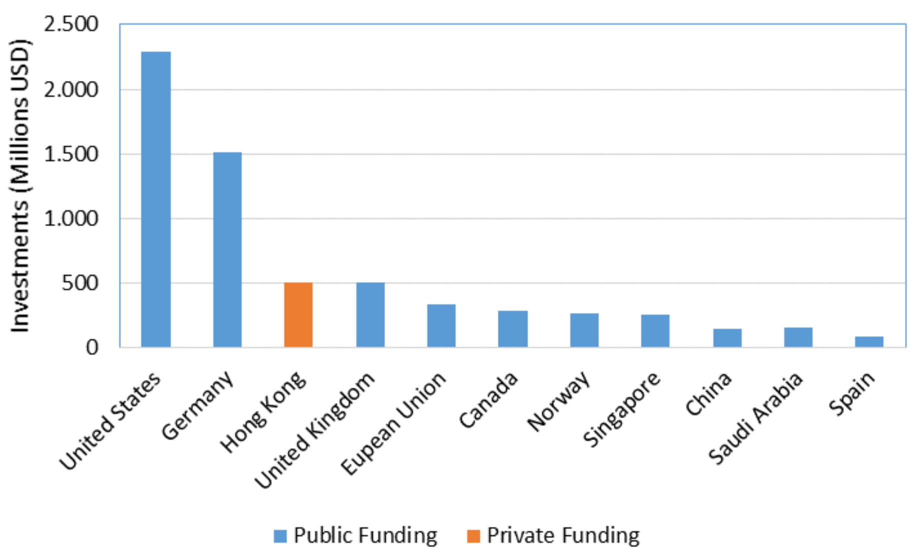

Figure 4. Covid-19 investment funding per country and fund type

Source: *Global Health Centre, (2021).*

Most companies received public funding, but most of these funds went to private companies. According to the Knowledge Network on Innovation and Access to Medicines (2021), the public sector and the Coalition for Epidemic Preparedness Innovations (CEPI), which is 97% public funding, invested approx. 5.6

billion USD in developing COVID-19 vaccines, from which nearly 95% was received by private companies, Janssen, Moderna, BioNTech-Pfizer, CureVac, and Novavax laboratories the most benefited (Table 1).

Table 1. *Covid-19 vaccine R&D funding (Millions USD).*

United States (2,289.5)	Janssen (1027.85)
	Moderna (957.3)
	Novavax (534.45)
	Innovio Pharma (98.5)
	Merck (38.03)
	HDT Bio Corp (8.2)
	Esperovax (0.61)
Germany (1507.21)	BioNtech/Pfizer (800.29)
	Curevac (741.68)
	IDT-Biologika (132.07)
	CEPI (1425.99)
Hong Kong (503.42)	Sinovac Life (500)
United Kingdom (499.59)	CEPI (1425.99)
	University of Oxford/Astra Zeneca (118.01)
	Scancell (2.59)
European Union (330.98)	Curevac (741.68)
	BioNtech/Pfizer (800.29)
	Osivax (20.34)
	Opencorona (3.48)
	CEPI (1425.99)
Canada (283.58)	CEPI (1425.99)
	Medicago (135.46)
	Canadian National Research Council (11.26)
	University of Western Ontario (0.75)
Norway (262.43)	CEPI (1425.99)
Singapore (250)	BioNtech/Pfizer (800.29)
China (145.05)	Sinopharm (144.96)
	University of Oxford/Astra Zeneca (118.01)
Spain (86.89)	CEPI (1425.99)

Source: *Global Health Centre, (2021).*

The logic behind the materialization of vaccines is the commercialization for profit-making. Patents are one vehicle, if not the most important, to secure the appropriation of knowledge by the owners of it. To overview the ownership of Nano enabled Covid-19 vaccines, we search in World Intellectual Property Organization (WIPO) through its database (Patentscope). We find 259 solicitations of patents with nanotech components to fight COVID-19; from the whole, 39% seek a PCT registration, to commercialize the knowledge acquired in different countries (Figure 5). Likewise, we find that the principal patent applicants are institutions and industries from advanced countries. In 41% of cases, they pursue the patent under the category of medical, veterinary, or hygiene.

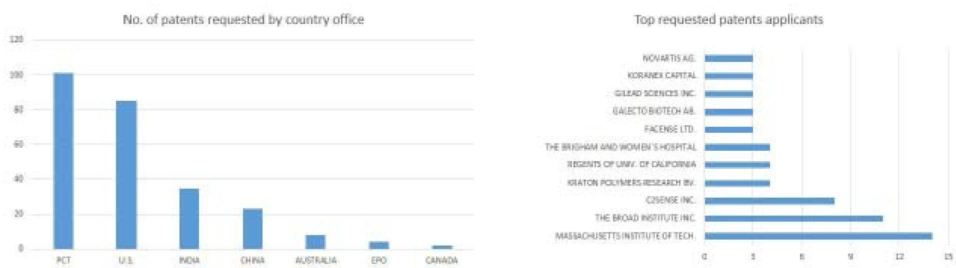

Figure 5. Patents requested by country (Left). Top requested patents applicants (Right).

Source: *WIPO Patentscope, August 2021.*

Research conducted by Kis and Rizvi (2021) suggests that the elaboration of the mRNA type vaccines produced by Moderna and BioNTech-Pfizer (developed with public funding) can cost up to USD 2.85 per dose, and USD 1.20 per dose for Pfizer. However, due to the lack of transparency of pharmaceutical companies, the exact cost of manufacturing is unknown. Researchers used a technique based upon computational s modeling to estimate the production cost to recreate the industrial requirements and the raw materials and human workers needed to manufacture these vaccines massively.

Data from Dransfield & Thériault (2021) show the investment from different countries to purchase vaccines and the surcharges at which pharmaceutical industries are selling vaccines. Companies have been charging up to 24 times the potential cost of production, with the highest reported cost paid by Israel. Although, many countries have no available data on how much they have paid for these vaccines. In addition, it must be considered that the prices of vaccines are subject to supply and demand, which is why countries such as Israel, United

States, and the European Union pay a higher cost in exchange for having monopolized the market and an immediate provision. In contrast, developing nations on the African and Latin American continents must wait for availability to purchase, without consideration of the Advanced Purchase Agreements (APA) that rich funding countries sign to develop vaccines (Table 2) (Wouters *et al.*, 2021; Çakmaklı *et al.*, 2021).

Table 2. Advanced purchase agreements between countries and pharmaceuticals. (Millions USD)

Biotech/Pfizer	Israel (352.5) European Union (11,340) Panama (84) United States (5972.48)
Curevac	European Union (2767.5)
Sanofi Pasteur/GSK	European Union (2790) United States (2100)
Moderna	European Union (2880) United States (4500)
Janssen	European Union (1700) United States (1000) African Union (2200)
Novavax	United States (1600)
Astrazeneca	European Union (1060) United States (1200) Brazil (942.65) Thailand (469.09)
Valneva	United Kingdom (858)

Source: *Global Health Centre (2021).*

According to the World Health Organization (WHO), before the COVID-19 pandemic, countries paid an average price of $0.80 per dose for all non-COVID vaccines. Even though all vaccines have differences and new vaccines methods cannot be directly comparable, one of the cheapest COVID 19 vaccines on the market, Oxford-AstraZeneca is nearly four times this price, the Johnson and Johnson vaccine is 13 times. The most expensive vaccines, such as BioNTech- Pfizer, Moderna, and the Chinese produced Sinopharm, are up to 50 times higher (Figure 6). Such is the case of the COVID-19 Vaccines Global Access (COVAX), which reported that for its first 1.3 billion doses, it paid an average price of $5.20 per dose, approximately five times more for vaccines.

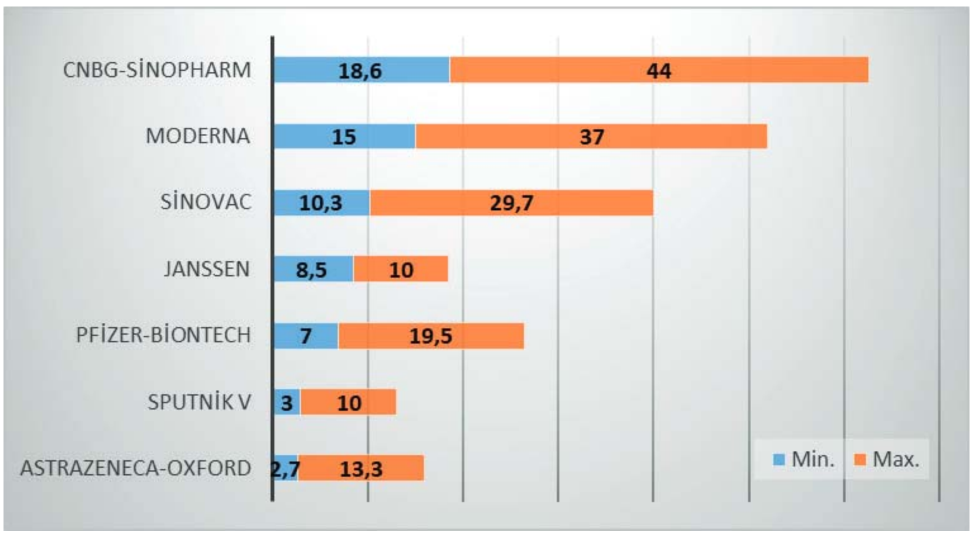

Figure 6. Minimum and maximum approx. cost (USD) of Covid-19 vaccines of different brands.

Source: *UNICEF, 2021.*

Besides, vaccine prices are only one of the multiple factors in the cost of immunization campaigns. There are other additional costs such as medication, with several surcharges depending on the country's conditions to treat the COVID-19 like Remdesivir (Veklury), an antiviral drug, Bamlanivimab, Etesevimab, Casirivimab, and Imdevimab (REGEN-COV), which are used for antibody regeneration as treatments for covid-19 patients. Pfizer spokesman declared that prices would rise again. He explained that the increase is due to the adaptations and changes they have to perform in their vaccines to attack the new variants of the virus. Nonetheless, the profits of these companies have increased exponentially (Table 3), and it is expected that in the coming years, they will rise again due to the new variations of the virus and the future changes in the vaccination policy.

Table 3. Profits of pharmaceutical companies for 1st. quarter 2021.

Brand	U.S. sales (USD)	Global sales (USD)
Pfizer-BioNTech	$2.038 billion	$5.833 billion
Moderna	$1.358 billion	$1.733 billion
AstraZeneca-Oxford	No U.S. sales	$275 million
Sinovac Biotech's CoronaVac	No U.S. sales	$264.5 million
Johnson & Johnson's	$100 million	N/A

Source: *Biospace, (2021).*

Another problem complements the circle of inequity in the production chain of nano-enabled vaccines against Covid-19: distribution. Research and development (R&D), patents, production, and commercialization, have a common denominator: inequality and inequity. Developed countries are what have secured more doses to the detriment of developing countries.

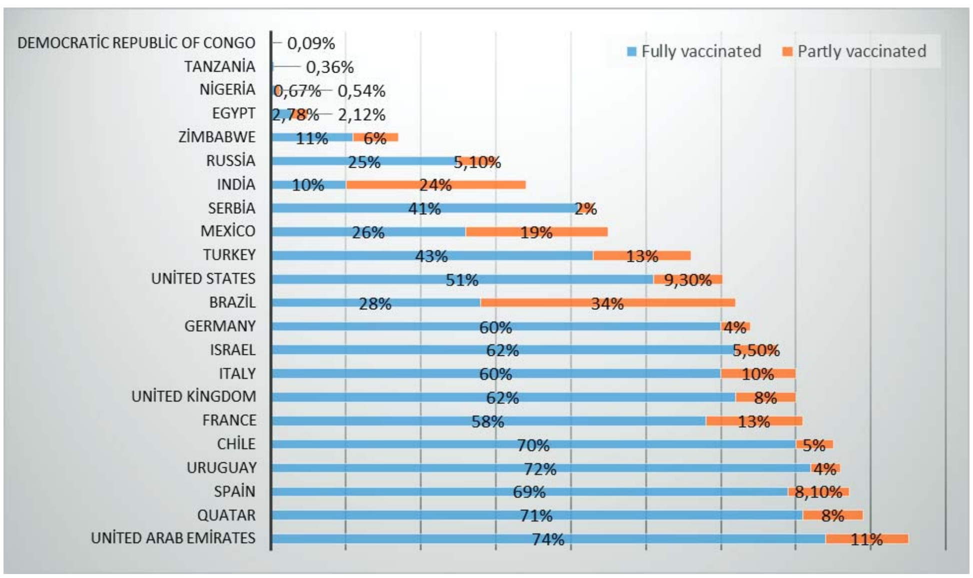

Figure 7. Percentage of people per country vaccinated against COVID-19.

Source: *Our World Data from Oxford University, August (2021).*

As shown in Figure 7, the countries with the highest percentage of population vaccinated (<60% with 1 or 2 doses) are mainly developed countries. Poor and developing countries are far below 1%, as in Tanzania and the Democratic Republic of the Congo. The same situation applies to the African and Latin American continents, oscillating in 20% to 40%. The difference is the result of the lack of agreements and resources for the acquisition of vaccines, which are also surcharged generating a very flagrant social distinction on those who can save themselves in an emergency.

Appropriate guidelines must be established to regulate monopolies and excessive profits that pharmaceutical companies secure from the chain of production of nano-enabled Covid-19 vaccines.

Conclusions

The world is under one of the worst economic and health crises in the last 100 years. Covid-19, until August 2021, has claimed the lives of more than 4.5 million people and infected about 220 million. The world's governments have advanced several initiatives to solve the problem. Still, the vast majority have opted for technological innovations and have ignored the economic structures that dominate the dominant mode of production. This chapter shows that vaccines are in the hands of transnational pharmaceutical corporations headquartered in the Global North. The so-called social benefit advances trougout the historical-structural logic of capitalism: i) ensuring extraordinary profit, ii) monopolizing knowledge (via patents), iii) increasing prices according to supply and demand dynamics and iv) controlling distribution to the detriment of the welfare of poor nations.The advancement of nano-enabled Covid 19 vaccines has benefited transnational companies and developed countries. They are the real winners behind the worst pandemic of the new century. Arguing that vaccines are the best solution to stop the global pandemic of Covid 19 implies advancing an economic structure where few are the winners, and the majority lose. This, in addition, projects an unfair distribution in the application of vaccines since the countries where they are developed are the ones that first ensure the doses to cover their population.

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