

Cozzi, Guido; Galli, Silvia

**Working Paper**

## Covid-19 Vaccines, Innovation, and Intellectual Property Rights

GLO Discussion Paper, No. 1095

**Provided in Cooperation with:**

Global Labor Organization (GLO)

*Suggested Citation:* Cozzi, Guido; Galli, Silvia (2022) : Covid-19 Vaccines, Innovation, and Intellectual Property Rights, GLO Discussion Paper, No. 1095, Global Labor Organization (GLO), Essen

This Version is available at:

<https://hdl.handle.net/10419/256807>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

# Covid-19 Vaccines, Innovation, and Intellectual Property Rights

Guido Cozzi\* and Silvia Galli\*

\*University of St.Gallen

June 1, 2022

## Abstract

Should the intellectual property rights on the first Covid-19 vaccines be temporarily lifted in applying the Trade-Related Aspect of Intellectual Property (TRIPS) flexibility? Is it right to grant the first generation of Covid-19 vaccines a special treatment from an IPR perspective? On what grounds?

By extensively reviewing the available medical and economic literature on the subject, this chapter will guide the reader step-by-step to the leading scientific, political, and cultural challenges in granting broad worldwide access to vaccination.

The accumulated delays in providing effective Covid-19 vaccine intervention in the low- and middle-income countries are ultimately responsible for the virus circulation at the global level and the proliferation of immunity-escaping variants. Therefore governmental rationality around the world would suggest any possible active policy tool to scale up the current vaccines supply.

However, not to prevent future investment in R&D, the governments should bear the cost of the expected increased industry obsolescence determined by a temporary patent waiver; this includes public patent-buy-outs and regulated public-private R&D partnerships.

*Keywords:* Vaccines, Covid-19, Pandemics, Patents, Innovation.

*JEL Classification:* I18, O30.

*“Many insisted that I patented the vaccine, but I didn’t want to. It is my present to all the children of the world. [...] You see, they killed me two wonderful nieces, but I saved children from all over Europe”.* Albert Bruce Sabin, American-Polish medical researcher, developer the oral polio vaccine, President of the Weizmann Institute of Science in Israel 1969–72. In this quote he referred to Amy and Deborah, killed by the Nazis in Białystok, Poland.

## 1 Introduction

Because of the undergoing historical period, talking about the "economics of vaccines" immediately triggers an identification between vaccines and Covid-19 in the public’s mind, as in most advanced economies, effective vaccinations campaigns against the Severe Acute Respiratory Syndrome coronavirus-2 (SARS-CoV-2) enormously impacted global public health and economic perspectives.

Spurred by this evidence, several contributions recently tried to capture the economic values of Covid-19 vaccines and specifically considered the interaction of different factors on the vaccination rollouts for a large set of countries. Determinant factors included: the initial impact of the outbreak in terms of incidence of the disease, fatalities, and intensive care unit admissions during the early phases of the pandemic; supply-side factors such as early procurement of vaccines doses; and the domestic production of vaccines (see Deb et al. 2022; among others).

The vaccine industry is one of the most concentrated in the world. Until 2019, four firms - Pfizer, Sanofi, GSK, and Novartis - earned more than 80% of the world vaccine revenues. Yet, their vaccines mainly served the richest 20% of the world population, strenuously protecting their monopolistic rents with the patents and other intellectual property rights instruments. For example, clinical trial results and other important documentation are held proprietary, which would render hardly effective a patent waiver. Such protection is not only crucial for vaccines, but for the many more other pharmaceutical products.

Unfortunately, the vaccine industry was considered one of the most vulnerable and least lucrative industries in the pharmaceutical sectors (Kremer and Snyder, 2003). Since demand often comes from governments, the firms that have invested massively in the research and development (R&D) of new vaccines are always at risk of a hold-up problem, in case governments refuse to pay a fair price for their jabs. This is an important reason why vaccine producer firms often refuse to directly sell their jabs to middle-income and low-income countries. This usually leaves the majority of the world population uncovered by vaccines, at the mercy of pathologies that a European or a North American would never experience in their life. Some producers offer vaccines to poor countries, most notably the Serum Institute of India (SII). SII is the world’s largest vaccine producers in terms of quantity, but the prices of its jabs are so low that its total revenue is negligible compared to the patent holders of the rich world. Yes, SII does a much better service to India and several other countries than its most

exclusive industry partners of the wealthy nations.

Covid-19 changed this scenario, because it massively increased the profitability of the vaccine industry. The combination of the pandemic severity and the huge macroeconomic costs of the non-pharmaceutical interventions (NPI) to contain the spread of the virus increased the demand for jabs to levels never imagined before. Billion of customers eager to vaccinate themselves as soon as possible appeared, with governments strongly supporting them. Starting as a small biotechnological German firm, BioNTech sold \$17 billion of its Covid-19 vaccine in 2021, with an estimated profits of at least half of it. BioNTech R&D costs in 2020, mainly devoted to its Covid vaccine, were \$645 million. The German government supported its R&D with \$445 million. This incredible scientific success is also the result of several years of university- and start-up companies research in the mRNA gene vaccines. Consequently, the research phase for the new vaccine was unexpectedly very fast: BioNTech received the genetic code of the new virus in January 2020 and its vaccine was ready for clinical trials by April 2020.

Pfizer was crucial in the clinical trial and approval stages, which attests on the division of R&D labor in this industry. Their vaccine was ready to use in the fall 2020. Pfizer/BioNTech set up a world record vaccine innovativeness and introduction speed, compared to the standard four to ten year vaccine development time.

Pfizer is the real winner of this vaccine patent race, deserving at least the merit of being fast in identifying a promising German firm and in offering a deal to share the profits and appropriate the relevant patent. No European pharmaceutical firm showed comparable intelligence abilities, thereby relegating Germany to a mere customer of a German-made but US-appropriated patent on the first top-of-the-art Covid-19 vaccine.

Another formerly unknown rising star is Moderna, born a decade ago as a small biotechnological firm with a young and committed team firmly convinced of the potential importance of mRNA technology. This American firm managed to introduce its vaccine shortly after Pfizer, consolidating the United States' advantage in this vital industry for the world. Moderna too capitalized on more than three decades of basic research in mRNA and related technologies, which obtained - thanks to the Bay Dole Act - several university and public institutions patents eventually non-exclusively licensed to Moderna.

In a press conference of 18<sup>th</sup> March 2021, Ursula von der Leyen declared "*We, Europeans, are excellent in making science with money. But we are not so good in making money out of science*". Spurred by the continental Europe's lack of science-industry coordination attested by Pfizer's takeover of BioNTech mRNA vaccine, the European Commission set up the Health Emergency Preparedness and Response Authority (HERA), to monitor pandemic emergencies and potential new vaccine candidates, with the aim of timely mobilizing European pharmaceutical developers. Quite frustrating for the European Union, post-Brexit United Kingdom ruled the world of the slightly less innovative but still highly effective and profitable vaccines, with its excellent science-industry coordination which allowed Oxford vaccine to get developed and commercialized

by British Astra-Zeneca. Continental Europe, along with India's SII, became the main manufacturing hub of the British patented Oxford/AZ vaccine.

Another very lucrative vaccine was developed and patented by Johnson and Johnson, which readily became popular because of its single-dose requirement.

China - with Sinopharm and Sinovac - and Russia - with Sputnik V - developed their vaccines. However, their effectiveness seems much lower, especially when facing the challenge of new virus variants. Consequently, as of March 2022, China still suffers a strict zero-Covid policy restricting international contacts and re-instating lockdowns. Russia still has a worryingly high virus mortality rate.

The Covid-19 pandemic vaccine high-income world market was dominated in 2020-2021 by the above-mentioned four vaccines, with Pfizer being the only previous member of the pre-Covid vaccine quadrumvirate. The strict enforcement of vaccine patents was set to generously compensate the patent race winners of the Covid-19 pandemic, but raise the legitimate question of whether they left almost 8 billion people at the mercy of a handful of profit-maximizing firms. This doubt is legitimate, because after a year and a half since production started half of the world population remained unvaccinated, the virus kept mutating and reducing the efficacy of the vaccines, and the world economy lost massive production and trade possibilities due to the NPI interfering all over the place. Moreover, while richer countries have been treated as preferential customers, the big vaccine producers have mainly ignored the poorer potential customers such as those of the sub Saharan Africa. India, after excruciating delays, managed to protect its population thanks to the unwavering effort of the SII.

More than 100 countries have asked WTO to temporarily waive Covid-related patents, to stimulate the entry of more firms worldwide and rump-up vaccine production. The wealthy countries blocked this proposal more times at the WTO. This reminded of the traditional poor-rich country opposition well-known in the pharmaceutical industry in the international political opposition to the application of the TRIPS, which led to the Doha Declaration (WTO, 2003). Then something completely new happened: the new White House administration, with president Biden, joined the patent waiver proposal in May 2021. This pathbreaking White House position makes history in the IPR doctrine, as the most innovative world had never declared its availability to partly sacrifice IPR to help the world. The former European parliament president Savid Sassoli echoed to "without taboos, to increase the production of vaccines". Eventually the European Union opted to oppose Biden's proposal at the WTO, leaving Covid-19 vaccine patents unsuspending.

Has the WTO strict enforcement of IPR slowed the worldwide vaccine Covid-19 production and herd immunity? Shall IPR be held responsible for new variants, like Omicron, to emerge in the unvaccinated part of the world? Would easier imitation have led to enough more production to immunize enough people in the world to eliminate the Covid-19 virus from the planet? Is economics able to answer these questions vital for the world population and macroeconomy?

This chapter tries to summarize what economics can add to the relationship between IPR and vaccine in a serious pandemic such as Covid-19.

The structure of this chapter is as follows: first, Section 2 reviews the central economic and medical literature on vaccines before the Covid-19 pandemic. Secondly, Section 3 analyzes the different scientific rationales that the available literature has so far proposed in support of a broader Covid-19 mass global-scale vaccine immunization campaign. Further to that, Section 4 derives the conditions that should be desirable from a social perspective to guarantee Covid-19 vaccines a differential treatment also from the point of view of IPR policy. In particular, Section 4 outlines a stylized model to instruct policy on the desirability of temporarily suspending vaccine patents. Depending on the crucial parameters of the model, it may or may not be desirable to waive vaccine patents temporarily. The user-friendly policy rule can readily provide estimates of the extra vaccine R&D public funding needed to compensate innovators of the future patent suspensions. Finally, Section 6 wraps up the conclusions.

## 2 The global market for vaccines

Before extending the analysis to the Covid-19 case, it is here useful to highlight the stylized facts of the economics of vaccines, which are obviously shared characteristics of the Covid-19 vaccine industry.

The first relevant stylized fact is that state authorities regulate the vaccine market highly. An extensive health economics literature highlighted the reasons for the traditional state interventionism in the vaccine industry. These reasons are mainly because the individual's private incentive to vaccinate may substantially differ from the public (state's) incentive to vaccinate from a social perspective. See Annemans et al. (2021) and Costa-Font et al. (2021), among others.

Vaccines that are efficacious against infection have aggregate health impact by reducing the burden of disease through direct protection of those vaccinated and reducing transmission, thus providing indirect protection to the population. This positive externality of individual vaccination on several other people's infections is not accounted for by the individual, who at most cares about his or her strict relatives. Hence, compared with most other available healthcare interventions, vaccines offer particular benefits in many ways. However, cohort-asymmetries affect the incidence of a given disease and the severity of the disease, complications, and long-term consequences. Unlike other medical technologies, vaccines are preventive. This simple consideration pins down private (non-state) demand for vaccines significantly when a specific cohort is asymmetrically affected by the disease. On the one hand, this calls for state intervention to correct this suboptimal tendency of the decentralized vaccine markets. However, in the absence of coercive interventions, the effectiveness of a vaccination campaign also requires broad societal support to reach herd immunity. See Betsch et al. (2013), Blanchard-Rohner et al. (2021), and Dewatripont (2021), among others.

From a development perspective, large-scale vaccination campaigns (e.g. rotavirus) showed that, when vaccines are made broadly available to the population, LICs are prone to support vaccines interventions effectively. This renders

the so-called anti-vax social attitude a middle- and high-income countries' feature. The public health value of vaccination depends on whether other treatments are available to reduce morbidity and mortality. Among the lowest spectrum of global income levels, the overall levels of health services and therapeutic options are so poor that, given the incidence of the pathogen on the population, mortality and long-term public health negative consequences of not vaccinating are much higher for LICs than for HICs; with a corresponding paradox for the vaccine becoming very cost-effective in LICs, but relatively less in low-middle to high-middle income countries (Annemans et al., 2021; and Hogan et al., 2021).

It is worthwhile to recall here the historical milestone achievements of vaccination in the fight against human life-endangering infectious diseases: the global eradication of smallpox (1980); the eradication of polio at the worldwide level, i.e. the reduction of polio cases by 99.5 % at the worldwide level (since 1988, thanks to the oral vaccine developed and unpatented by Albert Sabin); the first vaccine based on recombinant technology (1986); the first polysaccharide-protein conjugate vaccine (1987); the application of to adolescent vaccines (HPV, 2009); and, finally, the approval of the first two mRNA vaccines by the end of 2020.

Estimates show that actually vaccines prevent more than 20 currently life-threatening infective diseases, saving about 2-3 million deaths every year (Lobo, 2021). Although an overwhelming evidence shows that vaccines are among the most cost-effective of all public health technologies, in general, the standard public frameworks for the economic evaluation of public health programs tend to reflect more the private incentive for vaccination, which under-values the full range of health and economic benefits conferred by vaccines. Hence, the health economics literature duly developed a rich normative analytical framework to assess the monetary value of vaccines. This literature is also motivated by the fact that current national vaccination strategies would imply a structural underestimation of the economic benefits of vaccines compared to other pharmaceutical products (see Postma and Standaert, 2013).

Once individuated the causes of such under-estimation, better-informed policy-makers should opt for greater international cooperation and standardization of the procedures supporting global mass vaccination campaigns. The set of proposed useful analytical tools included introducing appropriate discounting techniques to estimate the long-term benefits of the vaccination programs, and introducing fairness considerations, which are able to heavily affect the attractiveness of a vaccination programs, like in case of the CIA's fake vaccination campaign organized in support of the captures of Osama Bin Laden (see Martinez-Bravo and Stegmann, 2021). See also Bos et al., 2004; Beutels et al., 2008; and Westra et al., 2012.

In general, lack of international coordination and poor standardization of vaccination programs are considered among the leading causes of inadequate cost-effectiveness of vaccine interventions, as has been shown by several studies on the decentralized introduction of rotavirus vaccination in neighbouring European countries (Netherlands, Belgium, UK, and France). See Jit and Edmunds (2007), Standaert et al. (2008), Bilcke and Beutels (2009), Bilcke, Van Damme,

and Beutels (2009); Rozenbaum et al. (2011).

Although vaccines are medicinal products centrally approved by international health regulatory authorities (the WHO checks and monitors the effectiveness and safety requirements of new vaccines), each country acts independently when it comes to market access. Market access and reimbursement procedures of medicinal products are diverse across states. National health budgets often distinguish between vaccines that are part of children’s basic vaccination programs (e.g., diphtheria-tetanus-pertussis vaccine, rotavirus vaccine), from vaccines that are part of dossier-specific reimbursement tracks (e.g. influenza vaccines), just like any other medical product.

As for August 20<sup>th</sup>, 2020, in Sub-Saharan Africa, fifteenth large epidemic outbreaks, other than Covid-19, were recorded. They are summarized by Tables 1. A and 1.B.

Table1.A: COVID and Non-COVID epidemics in SSA

COUNTRY	LARGE NON-COVID-19 OUTBREAKS	COVID-19 INCIDENCE	TOTAL POPULATION	POPULATION AGES 0-14 % OF TOTAL POPULATION	POPULATION % OF WORLD POPUL
<sup>*NC</sup> Angola	Measels, vaccine-resistant Polio (type 2)	1,000 < 4,999	32,866,268	46.40	0.42
<sup>*NC</sup> Benin	vaccine-resistant Polio (type 2), Lassa fever	1,000 < 4,999	12,123,198	41.94	0.16
<sup>*NC</sup> Burkina Faso	vaccine-resistant Polio (type 2)	< 1,000	20,903,278	44.37	0.27
<sup>*NC</sup> Burundi	Cholera, Measels	1,000 < 4,999	11,890,781	45.25	0.15
<sup>*NC</sup> Cameroon	Measels, vaccine-resistant Polio (type 2)	< 1,000	26,545,864	42.06	0.34
<sup>*NC</sup> Central African Republic	Measels, vaccine-resistant Polio (type 2)	1,000 < 4,999	4,829,764	43.54	0.06
<sup>*NC</sup> Chad	Measels, vaccine-resistant Polio (type 2)	< 1,000	16,425,859.	46.49	0.21
<sup>*NC</sup> Democratic Republic of Congo	Cholera, Ebola, Measels, Monkeypox, Plague, vaccine-resistant Polio (type 2)	5,000 < 14,999	89,561,404	45.80	1.15
Eritrea	unreported	< 1,000	6,081	23.98	0.0001
<sup>**</sup> Ethiopia	Cholera, Measels, vaccine-resistant Polio (type 2)	15,000 – 29,999	114,963,583	39.92	1.48
Gabon	unreported	5,000 < 14,999	2,225,728	37.26	0.03
Gambia	unreported	1,000 < 4,999	2,416,664	43.95	0.03
<sup>**</sup> Ghana	vaccine-resistant Polio (type 2)	> 30,000	31,072,945	37.13	0.40
<sup>*NC</sup> Guinea	Measels, Lassa fever vaccine-resistant Polio (type 2)	5,000 < 14,999	13,132,792	43.05	0.17
<sup>**</sup> Ivory Coast	vaccine-resistant Polio (type 2)	15,000 – 29,999	26,378,275	41.51	0.34
<sup>**</sup> Kenya	Cholera, Measels, Leishmaniasis	15,000 – 29,999	53,771,300	38.59	0.69
Lesotho	unreported	< 1,000	2,142,252	32.24	0.03
<sup>*NC</sup> Liberia	Measels, Lassa fever	1,000 < 4,999	5,057,677	40.37	0.07



Tables 1.A and 1.B present a list of 41 SSA countries, visually arranged from A (Angola) to L (Liberia) in Table 1.A, and from M (Malawi) to Z (Zimbabwe) in Table 2.B, respectively. For each country, the relevant table shows data about the presence in the country of recent Non-Covid-19 (NC) significant epidemic episodes (second column) and Covid-19 incidence (C – third column). Countries marked with the suffix \*N are affected principally by Non-Covid-19 epidemics. In contrast, countries with the suffix \*C have high Covid-19 incidence, but they are not significantly affected by Non-Covid-19 epidemic diseases. Finally, countries marked with the suffix \*\* (i.e. Ethiopia, Ghana, Ivory Coast, Kenya, Nigeria, Sudan, and Zambia) are perform poorly in both perspectives. They show both the presence of Non-Covid-19 large epidemic episodes and a high Covid-19 incidence.

Table1.B: COVID and Non-COVID epidemics in SSA

COUNTRY	LARGE NON-COVID-19 OUTBREAKS	COVID-19 INCIDENCE	TOTAL POPULATION	POPULATION AGES 0-14 % OF TOTAL POPULATION	POPULATION % OF WORLD POPULATION
Malawi	unreported	1,000 < 4,999	19,129,955	42.99	0.25
*NC Mali	Measels, Yellow fever	1,000 < 4,999	20,250,834	47.01	0.26
*NC Mauritania	Chrimean-Congo hemorrhagic fever Dengue fever	< 1,000	4,649,660	39.69	0.06
*NC Mozambique	Cholera, Measels	1,000 < 4,999	31,255,435	44.06	0.40
*NC Namibia	Hepatitis E	1,000 < 4,999	2,540,916	36.84	0.03
*NC Niger	Measels	1,000 < 4,999	24,206,636	49.67	0.31
**Nigeria	Cholera, Yellow fever, Measels, Lassa fever, vaccine-resistant Polio (type 2)	> 30,000	206,139,587	43.49	2.66
*C Republic of Djibouti	unreported	15,000 – 29,999	988,002	28.91	0.01
Guinea	unreported	1,000 < 4,999	13,132,792	43.05	0.17
*NC Republic of Congo-Brazzaville	Chikungunya	1,000 < 4,999	5,518,092	41.27	0.07
Rwanda	unreported	1,000 < 4,999	12,952,209	39.47	0.17
*C Senegal	unreported	15,000 – 29,999	16,743,930	42.59	0.22
Sierra Leone	unreported	1,000 < 4,999	7,976,985	40.34	0.10
*NC Somalia	Chikungunya, Cholera	1,000 < 4,999	15,893,219	46.15	0.20
*C South Africa	unreported	> 30,000	59,308,690	28.80	0.76
*NC South-Sudan	Chikungunya, Measels	1,000 < 4,999	11,193,729	41.33	0.14
**Sudan	Chikungunya, Dengue fever, Diphtheria	15,000 – 29,999	43,849,269	39.80	0.56
Tanzania	unreported	< 1,000	59,734,213	43.55	0.77
Togo	unreported	1,000 < 4,999	8,278,737	40.64	0.11
*NC Uganda	Cholera	1,000 < 4,999	12,952,209	39.47	0.17
*NC Union of the Comoros	Dengue fever	1,000 < 4,999	869,595	39.02	0.01
**Zambia	vaccine-resistant Polio (type 2)	15,000 – 29,999	18,383,956	44.02	0.24
*NC Zimbabwe	Anthrax	1,000 < 4,999	14,862,927	41.91	0.19

Table 2 lists the Non-Covid-19 epidemic diseases present in SSA, according to Coker et al. (2021), considered a rare disease, and for which no available prophylactic vaccine or therapy exists.

Table 2: neglected or orphan diseases in SSA

Country affected by epidemics as on May 2020	Population % of World population
<b>Chikungunya</b>	
Republic of Congo Brazaville	0.07
Somalia	0.20
South Sudan	0.14
Sudan	0.56
Total SSA susceptible pop. % of world pop.	0.99
<b>Lassa fever</b>	
Nigeria	2.66
Benin	0.16
Guinea	0.17
Liberia	0.07
Total SSA susceptible pop. % of world pop.	3.05
<b>Crimean-Congo hemorrhagic fever</b>	
Mauritania	0.06
Total SSA susceptible pop. % of world pop.	0.06
<b>Leishmaniasis</b>	
Kenya	0.69
Total SSA susceptible pop. % of world pop.	0.69
<b>Type-2 Polio</b>	
Angola	0.42
Benin	0.16
Burkina Faso	0.27
Cameroon	0.34
Central Africa Rep.	0.06
Chad	0.21
Congo, Dem. Rep.	1.15
Ethiopia	1.48
Ghana	0.40
Guinea	0.17
Ivory Coast	0.34
Nigeria	2.66
Zambia	0.24
Total SSA susceptible pop. % of world pop.	7.90

A disproportionately large burden of these infective diseases hits the 0-19 Sub-Saharan Africa (SSA) population, including Measles, type 2- Polio, and Yellow fever (Coker et al. 2021). In SSA, anyway, the fraction of population belonging to ages 0–14, which are considered among the highest virus spreaders, is significantly higher than in the rest of the world (fifth column), ranging from an average of 41.26% in Eastern and Southern Africa to an average of 43.12% in Western and Central Africa; against a world average of 25.48% (WDI, 2021)

By looking at these data, the full extent of the pervasiveness of industry well-documented market failures dramatically emerges. In fact, as for type 2- Polio, Lassa fever, Leishmaniasis, Crimean-Congo hemorrhagic fever, and Chikungunya; they are considered rare diseases at the world level, as they only affect developing countries which contribute to a small part of the world population (Table 2). Consequently, they are practically ignored by the R&D efforts of profit-oriented pharmaceutical multinational companies (MNCs), as they are not considered a profitable investment, at the point that, at the moment, no approved prophylactic vaccine is available for such diseases.

For example, in SSA, Chikungunya epidemics are considered active in four countries (Republic of Congo Brazaville, Somalia, South Sudan, and Sudan), resulting in 0.99% of the world population. Anyway, in 2007 a first Chikungunya outbreak (250 cases, of which one mortal) hit a HIC, Italy, followed by a second acute episode (500 infections, with no mortality), always in Italy, in 2017. Similarly, SSA markets for potential prophylactic vaccines for Lassa fever, Leishmaniasis, and the Crimean-Congo hemorrhagic fever constitute only 3.05%, 0.69%, and 0.06% world population, respectively. However, as regards type 2- Polio, quite worryingly from a global public health perspective, it is active in thirteen SSA countries, together amounting to the 7.90% of global population.

Also, for this reason, the current public debate shows great interest in the possibility that public research institutions actively engage in vaccine development and production to cover the many documented cases where the private sector lacks the adequate motivation to produce vital medical products. Anyway, the impact of legislative innovations like the Bayh-Dole Act has generated diffused concern about moving intellectual property protection upstream to basic innovators (see Cozzi and Galli, 2017 and 2021).

### **3 The Covid-19 Vaccine Case from a World Perspective**

The impact of the Covid-19 world pandemic on the global economy has been unprecedented in modern non-war times. The immense negative macroeconomic impact drove governments to implement effective vaccination strategies in the shortest possible time laps.

From a global Covid-19 perspective, particularly worrying appears to be the cases of Nigeria, with less than 5% of the population vaccinated as of March 2022, and Ethiopia, also with less than 5% of the population vaccinated as of March 2022, which separately account for the 2.66% and 1.48% respectively of the world population (see Coker et al. 2021).

In SSA anyway, the fraction of population belonging to ages 0-14, which are considered among the highest virus spreaders, is significantly higher than in the rest of the world: it ranges from 41.26% in Eastern and Southern Africa to an average of 43.12% in Western and Central Africa, against a world average of 25.48% (WDI, 2021). Most infective diseases hitting harder on the young population also cause potentially severe impediments to human capital accumulation. This hits especially in LICs, where infections targeting more formative, younger ages can result in widespread cognitive underdevelopment, lower school attendance, worse educational attainment outcomes, and less attractive employment prospects as adults. Connolly et al. (2012) and Kotsopoulos et al. (2015) considered the long-term beneficial fiscal consequences of protecting the youth population from disease by appropriate vaccination, in the case of the rotavirus infection and the Human Papilloma Virus (HPV) infection, respectively.

However, since from February 2020 up to October 2020, there were no vaccinations nor proven prophylactic medicines against SARS-CoV-2, nor proven treatments for recovery from Covid-19, the Non-Pharmaceutical (NP) methods of epidemiological control largely adopted included school closures as a public health policy routine; with resulting negative consequences in terms of human capital accumulation also in the HICs (see Agostinelli, Doepke, Sorrenti, and Zilibotti, 2022; Chetty, Friedman, Hendren, Stepner et al. 2020; McBryde et al., 2020; Karatayev et al., 2020; Brooks-Pollock et al., 2020; and Head et al., 2020.).

Back in 2005, Smith, Yago, Millar, and Coast (2005) proposed to collect and estimate all economic consequences of infective disease episodes (including changes in supply and consumption behaviors, the effects on taxation, and the altered use of labor and capital), within a computable general equilibrium model to assess the costs of international public health emergencies, though recent contributions highlighted the empirical difficulty in estimating the whole magnitude of the macroeconomic effects of the recent Severe Acute Respiratory Syndrome (SARS) outbreaks. See Beutels et al.(2003), Beutels et al. (2008), Beutels et al. (2009), Smith et al. (2009), Keogh-Brown et al. (2008), Keogh-Brown et al. (2010), and Prager et al. (2017).

The most recent utilitarian welfare with Covid19-induced-mortality macroeconomic approach interpreted the Covid-19 economic shock as a reduction in the productivity of the quarantined individuals. Hence, these models usefully captured the aggregate utility loss from intertemporal infection increases (without vaccines) and the related increased severity of the NP interventions. Anyway, in this setting, aggregating individual well-beings with cohort asymmetry with respect to the pathogen is far from straightforward from a normative point of view. See Acemoglu, Chernozhukov, Werning and Whinston (2021); Jones, Philippon and Venkateswaran (2021); Boucekkine, Caravajal, Chakraborty and Goenka (2021); Boucekkine, Chakraborty and Goenka (2021) among others.

This chapter systematically reviews the health and economic modelling literature on Covid-19 vaccination, academically or independently developed to serve public health policymakers in their efforts to minimize Covid-19-related mortality, transmission, and morbidity outcomes. In addition, they support governments worldwide to achieve shared vaccination goals at the global and national levels.

To the extent that in the real world, what is perceived as urgent does not necessarily reflect what is essential, and this is particularly often true concerning public health policies; at the current global fight against Covid-19, the big elephant in the room is to ensure decent vaccination coverages for LICs. In fact, according to the World Health Organization (WHO), an inclusive global access to Covid-19 vaccines, along that suggested by Covax vaccine-sharing initiative, is also the optimal strategy to reduce the potential global mortality from variants (viral strains hosting genetic mutations that increase transmissibility, change immune response, or affect the disease severity).

Moreover, to correctly frame the theme, one should note that at least for three main reasons, the Covid-19 vaccine's case is a special case within the

economic literature on vaccines, particularly from an innovation-based scholar's perspective. First, from a production point of view, innovative mRNA vaccines result from a change in the technological paradigm of vaccines production. This change massively draws upon public investment in basic research in advanced leading research countries. After combining ex-ante public funding and guaranteed government pre-orders, about \$5.75 billion for Moderna and \$2.5 billion for Pfizer/BioNTech.

The mRNA technology is particularly appreciated because it provides the highest coverage against contracting SAR-Cov-2 and because the manufacturing of the intermediate components of mRNA vaccines is less complicated than the "traditional" (cell-based, non-mRNA) vaccines. Indeed, the mRNA molecules are far more straightforward than proteins and the human body artificial viral proteins themselves, which are the intermediates in the traditional technologies (Lobo 2021).

For this reason, mRNA vaccine manufacturing can take place in much smaller bio-reactors (e.g., 30-50 litres) than those generally adopted for traditional vaccine production (e.g., 2000 litres), according to Wen, Ellis, and Pujar (2015), and Park and Baker, (2021). The production facilities (installed capital and equipment) can be an order of magnitude smaller, and, as a consequence, the financing costs for vaccine producers are lower. Most importantly when considering the welfare increases deriving from raising the actual supply capacity, because of the small-implant-scale nature, setting-up production processes and covering investment expenses is cheaper for mRNA vaccines; and the production process can be quickly re-targeted for new variants, or even for new viral threats (see Pardi et al., 2018). BioNTech re-converted a cancer biological manufacturing facility into a Covid-19 vaccine manufacturing facility, with staff re-training, in six months.

From an innovation perspective, mRNA vaccines could be considered patented basic research. In fact, their potential application goes far beyond Covid-19 vaccines, as they constitute an almost general cost-saving production technology, viable of utilization for a broad set of different vaccines (Pardi et al., 2018; among others). Since Green and Scotchmer (1995), various theoretical and empirical approaches to sequential innovation in economics warned public regulators against the possibility that blocking patents could emerge in strategic basic R&D sectors, with the effect of restricting access to basic research sectors hampering future research avenues (Aghion and Howitt, 1996, Scotchmer, 2004, Chu et al., 2012, and Cozzi and Galli, 2014). Hence, mRNA technologies are an outbreak in basic scientific research, which should be adequately rewarded, but with a careful eye on the possible emergence of wicked incentives from an aggregate innovation perspective. See also Kiedaisch (2015); Gersbach, Sorger and Amon (2018); Heinemann (2019); and Akcigit et al. (2021).

Hence, understanding that mRNA vaccine manufacturing happens on a smaller scale, and it is cheaper and faster to establish compared to non-mRNA technologies is the crucial first step to analyze the impact of policies both from the perspective of the innovators' incentives and from the point of view of the aggregate welfare gains deriving from the same innovations. See Kis et al. (2020a),

and Kis et al. (2020b).

Secondly, the unprecedented global economic crisis generated by the Covid-19 world pandemic put considerable pressure on both vaccines producers and intergovernmental health organizations to guarantee Covid-19 vaccination to the world population in the shortest time lapse. Never before modern national health systems had to deal with such a globalized public health challenge. Trade interdependencies with unvaccinated countries impose a sizable economic drag on the vaccinated countries (Çakmaklı et al. 2021).

Finally, the public health value of vaccination depends on the population's risk profile, among other things. Hence, based on purely demographic considerations, the expected beneficial impact of Covid-19 vaccination is most significant in high-income countries (HICs) since these have the largest elderly populations and, therefore, the highest propensity to pay the public costs of mass vaccination campaigns.

This observation renders the field of Covid-19 vaccines particularly exposed to age-bias considerations at the national and international levels. If from a technological perspective, Covid-19 vaccines are considered a change in the paradigm of vaccines production (in particular the most innovative mRNA-vaccines); from a global demand perspective, the requests of Covid-19 vaccines are distorted in favour of HICs, who are also those countries who can afford to pay more. Unlike retrovirus vaccines, whose introduction effectively increased children's life expectancy in Sub-Saharan Africa thanks to GAVI Alliance, Covid-19 vaccines are freely provided within the national health systems of HICs. This is in line with the general observation that welfare states of HICs are considerably more age-oriented than those of LICs. Therefore, assessing the economic impact of the Covid-19 vaccines in HICs should take into account that aggregate productivity also includes quantifiable non-market productivity gains attributable to unpaid activities often performed by the elderly population, such as volunteering or philanthropic work; caregiving for children, grandchildren, or sick people.

In the global strategy against Covid-19, the focus of biomedical scientists and virologists has been reaching herd immunity by vaccination early enough. Most notably, before that, the global circulation of the new coronavirus implied that the SARS-CoV-2 wild strain changes in such unpredictable ways, meaning the re-exposure of those previously infected or vaccinated individuals. See Caldwell et al.(2021) for a recent extensive survey of the available research material on epidemiological mathematical modelling of Covid-19 herd immunity, with vaccines and different virus variants scenarios.

To quantify the level of population immunity (e.g., vaccine coverage) needed to achieve herd protection, epidemiological modellers calculate the Herd Immunity Threshold (*HIT*). The *HIT* is a helpful tool to guide vaccination campaigns, which in its simplest expression, assumes homogeneous mixing (i.e., assumes that contact rates among all individuals in the population are uniformly distributed) and implies the following well-known formula:

$$HIT = 1 - \frac{1}{R_0},$$

where  $R_0$  denotes the average number of secondary infections from each infectious individual in a fully (or partially) susceptible population. In other words, " $R_0$  is the basic reproduction number, or the average number of susceptible individuals that are infected by a single infected individual." (Agarwal and Reed, 2021).

In practice,  $HIT$  varies by context, as contacts and infections do not distribute uniformly within populations based on individual and aggregate factors like age, behaviours, contact patterns, physical distancing, naturally achieved immunity and vaccine coverage. Hence, for Covid-19, the focus should be on attaining substantial levels of herd protection to slow down the spreading of the disease. Early Covid-19 studies estimated a  $HIT$  of 60 – 70% based on initial  $R_0$  estimates of 2.5 – 3.5 (Wu et al., 2020; Musa et al., 2020; and Alimohamadi et al., 2020). However, the first SARS-CoV-2 Alpha variant has been estimated to be 60% more transmissible than the wild-type SARS-CoV-2 strain, implying a  $HIT$  of 80% (Davis et al., 2021).

Agarwal and Reed (2021) slightly extend the previous model to refine its empirical results. Knowing, as of time  $t$ , the values of the infection basic reproduction parameter  $R_{0t}$ , a given population fraction of infected, a given reinfection rate  $f_t$  for infected, and vaccine effectiveness  $E_t$ . Then, Agarwal and Reed (2021) show that the minimum amount of vaccinated population fraction guaranteeing herd immunity,  $vaccinated_t^*$ , is obtained with this formula:

$$vaccinated_t^* = \frac{1 - \frac{1}{R_{0t}} - (1 - f_t)Infected_t}{E_t}$$

Unlike Agarwal and Reed (2021), let here all parameters change over time. For example, vaccine efficacy in a population can drop after six months from the last vaccine, etc.. Base immunity is  $B_t = Infected_t + Vaccinated_t$ . Hence the effective reproduction number is  $R_t = (1 - B_t)R_{0t}$ . Herd immunity is obtained when  $R_t = 1$ .

Calibrating parameters realistically, they find that a vaccination threshold  $vaccinated_t^* = 45 - 60\%$ .

Much of future global pandemic scenarios will depend on how the viral strains evolve according to natural selection. Caldwell et al.(2021), among others, note that, in general, viruses become more transmissible and less pathogenic over time. They often evolve into endemic diseases, and similar mutations can arise in different world regions, given the exposure to worldwide similar natural selective pressures.

As this process of natural selection leads to multiple co-circulating variants, with varying transmissibility, severity, and responsiveness to pharmaceutical interventions, alternative aggregate epidemiological outcomes are susceptible to prevail. In particular, when co-circulating strains provide cross-immunity (i.e., infection from either variant confers high levels of immunity to both strains), disease models show that:

1. viral competition favours variants with higher  $R_0$ , leading to *strain replacement* (Keeling and Rohani, 2008);

2. when strains display similar  $R_0$  values, *epidemic cycles* are likely to emerge, which mimic seasonal influenza epidemics cycles (Gupta et al., 1998; Gomes, Medley, and Nokes, 2002; Keeling and Rohani, 2008).

Fitting mathematical models with the time series of strain infection incidence (in the context of SARS-Cov-2, this means the incidence of the variances so far identified, from Alpha to Omicron) allows epidemiologists to estimate strain-specific growth rates,  $R_0$ , and the extent of cross-immunity conferred to other strains (Davis et al., 2021). Basically, achieving significant levels of global herd protection implies shifting the focus on keeping the global cross-strain average infection rate  $R_t$  below one, allowing to achieve both low levels of sustained viral transmission (causing endemic cycles), and acute epidemic episodes contained in their absolute magnitude.

Using a disease model that considers long-term immunity and homogeneous mixing in the *HIT*, Caldwell et al. (2021) showed that herd immunity can become unattainable with co-circulating viral strains with increased transmissibility and/or immune evasion. For example, a vaccine that is 90% effective at reducing a strain-specific infection transmission (e.g., Moderna against the SARS-Cov-2 wild-type strain) would require at least 62% vaccine coverage to achieve herd immunity; but if vaccine-escaped viral mutants lead to a vaccine efficacy less than 60% (the authors provide evidence that this is the actual tendency of SARS-Cov-2 ongoing natural evolution), diffused herd immunity cannot be achieved through vaccination alone.

According to this realistic scenario, to prevent regular or periodical hospital congestions, with still relatively high death tolls over the following years, countries will hamper the transmission of SARS-Cov-2 variants among the population by regular vaccine booster doses (like for the seasonal influenza viral strain). Also, likely will be new socially and economically painful NP epidemiological control methods (i.e. broad restrictions to people's liberties, lockdowns, sectorial business shut-downs, school closures, etc.) to buffer the most acute phases of the epidemic due to the increased  $R_t$ . See Goenka and Liu (2013 and 2020); Goenka, Liu, and Nguyen (2014 and 2021); and Goenka (2021).

Allocating available vaccines doses in proportion to each country's population size (compared to the current practices favouring HICs) is close to the optimal strategy (Hogan et al., 2021), and could double the global number of deaths averted (Chinazzi et al., 2020):

*"If high-income countries can preferentially obtain a large proportion of the available vaccine doses at the expense of lower income countries then we would expect an additional 900 deaths per million from this less efficient global allocation". Hogan et al. (2021)*

Of the about 1.6 billion vaccine doses administered to date only 0.3% was destined to the poorest countries. The current state of allocations of Covid-19 vaccines doses to the LICs has been described as worrying and requiring immediate action from governments of both developing and developed countries, as



the Covid-19 pandemic will not be over unless it is assured that vaccines are made available everywhere (Gurwitz 2021).

As amply discussed, the vaccines sector is considered one of the most vulnerable and probably the least lucrative industry in the pharmaceutical sectors (see Kremer and Snyder, 2003). Here, pervasive market failures prevent the industry from satisfying the effective demand, thereby triggering periodic shortages of products which are vital for public health and economic development: historically, vaccines supply shortages have been more the rule than the exception (see Lobo, 2021; among others).

A few large producers dominate the global vaccine production, consistently with significant scale economies and non-competitive behaviours. Large ex-ante investments in both R&D and specialized physical capital and equipment are required to install a critical productive capacity. Consequently, it is rational for operating vaccines producers to try to smooth the utilization of the installed productive capacity over the medium-long run and postpone reaching herd immunity in the HICs. The latter are market segments primarily targeted by pharmaceutical MNCs' price-setting strategy. Just as Adam Smith noted in his 1776's classics, it would indeed not be judged as wise, someone who expects their dinner from the benevolence of the butcher, the brewer, or the baker (Smith, 1776).

Given the global aggregate shortage of vaccines, prioritizing Covid-19 vaccination within and between countries has been a source of public health concerns and an ethical challenge for international policy-makers. Forslide and Herzing (2021) focussed on characterizing the inter-temporal trade-off between reaching herd immunity and the price-setting behaviour of an influenza-type vaccine's monopolistic producer. But, in a closely related epidemiological paper, Hogan et al. (2021) analyze a global epidemiological model with different vaccination scenarios for different age groups to best assess the intra-country age profile and the global allocation of Covid-19 vaccine doses. Like Forslide and Herzing (2021), during the first stages of the pandemic, if the target is to reduce mortality, HICs should prioritise covering their old-age individuals. During a more mature phase of a successful vaccination campaign, anyway, provided that the target is to eradicate SARS-CoV-2, younger individuals, who are the highest spreaders, should be given priority; and vaccines doses should be allocated proportionally to population also to LICs. Current COVAX plans favour a global allocation strategy that prioritises the highest risk groups – including the elderly – and suggest an "equitable" vaccine allocation strategy. Each country receives doses in proportion to its population size and epidemic status.

According to Forslide and Herzing (2021), the middle-aged should have priority if economic productivity is the main target. In fact, vaccines enhance labour force productivity in many ways. In particular, because vaccines can prevent diseases and their resulting disabilities, they contribute to aggregate productivity by lowering absenteeism at work, which not only lead to lost production output but also increased unemployment expenses for the social welfare system. See also Bärnighausen et al. (2014), Bilcke et al. (2014), and Annemans et al. (2021).

Recently, the empirical study of Deb et al. (2021) used cross-sectional variation in vaccination rates to assess the expected impact of the virus varying into more transmissible strains (with a higher  $R_0$ ), on a large set of countries. Consistently with the prediction of Caldwell et al. (2021), their results suggest that from a medium-term perspective, as long as the vaccine distribution is unequal across countries, no country is safe, even those achieving high vaccination outcomes. The rapid spread of the Delta variant from India to neighbouring countries is considered the paradigmatic case of cross-border spillovers from protracted epidemic waves: the Delta variant became the dominant coronavirus in Asian countries and in North America over a 1-3 months period after becoming the dominant variant in India.

The central novelty of Deb et al. (2021) consists in constructing daily proxies of "foreign" Covid-19 cases and vaccines in neighboring countries, based on geographic proximity and realistic trade linkages. New Covid-19 cases in neighboring countries contribute to an increase in a country's own infections, but on the positive side, there are considerable positive spillovers from increased vaccinations in neighbouring countries. Such spillovers are compelling motivation for international cooperation to scale vaccine production at the global level, and to ensure adequate distribution of vaccines to all countries, including by sharing excess doses (Lamy, 2020).

In a related study, Çakmaklı et al. (2021) also focus on international trade, production linkages, and unequal vaccines allocations. This study estimates that the global economic costs due to missing to vaccinate 50% of the LICs' population might be as high as \$3.8 trillion. Hence, making the vaccine globally available "(...) *is not an act of charity, but an act of economic rationality for the advanced economies to get involved in the efforts for an equitable global vaccine distribution*" (Çakmaklı et al. 2021, p.3).

A country's epidemic circulation not only impacts its production and employment as a pure domestic supply shock, but it also impacts the production of intermediate inputs imported by other countries. To capture these international value-chains spillovers, Çakmaklı et al. (2021) incorporated the global intersectoral input-output linkages into a Susceptible-Infected-Recovered (SIR) epidemiological model. This approach allowed them to quantify the cascading effect of sectorial supply shocks in different countries via global value chains and international production linkages. When vaccination is complete, sectorial demand and supply shocks get immediately re-absorbed in vaccinated countries. As a consequence, the economic costs of the pandemic due to negative domestic sectorial demand and supply shocks disappear in vaccinated countries; however, the costs arising from the international trade network persist as long as foreign countries are not vaccinated.

## 4 The Case for a Covid-19 Patent Waiver

This section analyzes whether it should be desirable (or not) from a global social perspective to guarantee Covid-19 vaccines a differential treatment also from the

point of view of IPR policy.

"Intellectual property" is a notion referring to several different legal instruments: patents, trademarks, copyrights, designs, and undisclosed information are some examples of IPR provided for under the TRIPS Agreement (see Watal, 2001; among others.) Patents and undisclosed information are forms of intellectual property closely relevant to vaccines. For example, patents (Articles 27-38 TRIPS) protect inventions. In contrast, a broad class of undisclosed information (Article 39 TRIPS) potentially includes both information relating to vaccine production processes and aspects of vaccine clinical trial or other relevant test data.

Recently, different global political stakeholders (including the European Parliament and the US President Joe Biden) demanded the temporary lifting of IPR protection for Covid-19 vaccines, to address vaccines production bottlenecks, and hence to accelerate the global vaccine rollout. In his statement of Nov. 26<sup>th</sup> 2021 about the Omicron variant, the US President Joe Biden said:

*"I call on the nations [...] to meet the U.S. challenge to waive intellectual property protections for Covid vaccines, so these vaccines can be manufactured globally. I endorsed this position in April; this news today reiterates the importance of moving on this quickly".*

On October 2<sup>nd</sup> 2020, the Indian and South African governments presented a formal proposal for a patent waiver, following specific provisions of the agreements on TRIPS. See WTO (2020). The waiver would prevent the current patent holders of Covid-19 vaccines from blocking vaccine production elsewhere on the grounds of patents and allow countries to produce Covid-19 medical products locally or import or export them more easily. More than one hundred of the 164 WTO member states declared themselves in favour of India and South Africa's proposal for a temporary waiver of patents on Covid-19 vaccines as part of the agreements on TRIPS. Still, after intense bilateral and multilateral talks on this issue, the consensus required by the WTO has not been reached.

In fact, all recent Covid-19 patent waiver proposals encountered a numerically limited, but still influential opposition, from a part of the international IPR policy experts' community (aligned with the arguments of vaccines' producers), which ultimately raised the point that the potential detrimental effect of a patent waiver on future innovation's incentives may overcome the beneficial effects of an effective global-wide Covid-19 vaccination coverage. In particular, they suggested that by reducing the return on investment in R&D; the temporary patent waiver would permanently dismantle the same IPR system that provided the products needed to put the pandemic to an end; penalize pharmaceuticals; stifle biomedical innovation; and finally deter future investments in R&D. Thambisetty et al. (2021) point out the need to accompany mandatory IPR measures on Covid-19 vaccines with other incentives to pharmaceutical MNCs to share knowledge. In particular, they argue that without sufficient active engagement by the pharmaceutical industry (the current owners of IPR, data and know-how to address the pandemic), mandatory mechanisms like a patent waiver or compulsory licences could result extremely complex and time-consuming to implement in additional vaccines production. See also Gurry

(2020)'s considerations the non-IPR barriers to access to vaccines a therapeutic products against Covid-19.

The argument was advanced, among others, that traditionally IPR did not significantly impact the price-setting strategies of vaccine manufacturers; for example, in the case of the recombinant DNA Hepatitis B vaccines, where the maximum patent licence royalty rate was 15%. However, it appears that the recombinant DNA Hepatitis B vaccine experienced effective price competition from a plasma-derived Hepatitis B vaccine, independently provided by two South Korean manufacturers (the Cheil Sugar Company and the Korean Green Cross Corp.).

Interestingly, Cuba developed two homemade mRNA-Covid-19 vaccines: Abdala and Soberana 02, both ideally given in three doses. By the end of 2021, the country immunized more than 90% of its population, and it started exporting the Cuban mRNA-Covid-19 vaccines to partner countries, conditional to the WHO approval. According to the evolution of the epidemics, Cuba saw a big spike in the SARS-CoV-2 infection cases in August 2021 – when Cuba's vaccine coverage was still relatively low –, but new infections in the country have since then continuously declined and remained low. Although without further empirical investigation, it is difficult to gauge how much of this success is to be due to the vaccines, the virus's suppression coinciding with the country reaching high vaccine coverage is a positive sign. See Reardon (2021); Toledo-Romani et al. (2021); Chang-Monteagudo et al. (2021); Head (2021); and Taylor (2021). Currently, Vietnam and Venezuela have received Abdala doses, while both Abdala and Soberana 02 doses have been sent to Iran for clinical trials. Nicaragua has given emergency authorization to both Cuban vaccines; Mexico and Argentina declared themselves interested in using these vaccines.

A crucial step will be the expected WHO approval, and after that, new data will be released which will allow the experts to evaluate the efficacy of the Cuban Covid-19 vaccines. Until then, and probably also afterwards to some extent at least, it is good academic practice to take the concerns related to the effective productive capacity of the outsider competitors very seriously. In fact, potential challenges with scaling up mRNA vaccines production include the limited availability of industrial specific know-hows and skilled human capital, which are both essential to implement the new technology, along with quickly sourcing raw materials (e.g., the cationic lipid) in the required quantities.

The problem is exacerbated anyway by the fact that patented vaccines have their fundamental components and background technologies patented as well, which complicates, even more, the outsiders' ability to imitate the final technology (see Namboodiri 2020; among others). Also, for this reason, it is strategic for LICs to build universal medical productive capacities and welfare systems, to share knowledge and technologies, to prioritize the production and the distribution of a broad set of home-made pharmaceutical inputs, medicines, and vaccines; along the model pursued by Cuba, which anyway was forced into developing medical and sanitarian autarchy by trade restrictions. See Augustin (2022); Head (2021); and Meredith (2022), among others.

To try to overcome the problem of multi-patented technologies used in the

final Covid-19 vaccines, the approval of a Covid-19 Technology Access Pool (C-TAP) was proposed during early stages of the pandemic (see de Menez, 2021). Ideally, C-TAP should have been working as a voluntary licensing scheme for “*existing and future rights in patented inventions and designs, as well as rights in regulatory test data, know-how, cell lines, copyrights and blueprints for manufacturing diagnostic tests, devices, drugs, or vaccines*” related to Covid-19 (Munoz Tellez, 2021). In fact, the global R&D system and the business model of pharmaceutical companies are based on the enforcement of their IPR over drugs and other knowledge-based assets, but, as Suzanne Schotchmer noted back in 2004, the legal rights conferred by patents economically corresponds to a veto power over the manufacturing of a patented technology (see Schotchmer, 2004). As a consequence, the international community has a political due to first look after “cooperative” solutions together with the pharmaceutical MNCs, before considering moving towards more drastic and controversial measures, like a temporal patent waiver or compulsory licensing. See Thambisetty et al. (2021).

Although initially the C-TAP proposal was received with great enthusiasm, over time optimism has diminished due to the low commitment of developed countries and lack of interest from the pharmaceutical MNCs (de Menez 2021). For this reason, the WHO launched the Access to Covid-19 Tools Accelerator (ACT): a global collaboration program designed to accelerate development, production, and equitable access to Covid-19 tests, treatments, and vaccines (Lamy 2020). The ACT-Accelerator is structured on four pillars: diagnostics, treatment, vaccines, and health system strengthening. The vaccine procurement pool (Covax) is the vaccines pillar; the Coalition for Epidemic Preparedness Innovations (CEPI) coordinates vaccine development and manufacturing; the WHO oversees policy and allocation issues, and the GAVI Vaccine Alliance, is responsible for procurement and delivery of vaccine doses. Essentially, Covax is a pool for procurement and equitable distribution of vaccines: by aggregating the demands of different countries and supporting different suppliers, it is meant to reduce the purchase prices and avoid the natural risks of developing and producing vaccines, as too global supply shortages.

In the recent past, bulk purchasing and procurement processes proved very successful in reducing the price of the Hepatitis B vaccine (see Garrison, 2004), and further alternative mechanisms have been proposed to facilitate access to patented vaccines included tiered pricing finally the recourse to compulsory licensing.

Tiered pricing is a traditional mechanism for facilitating access to vaccines. This is in part because parallel importation tends not to take place given the “cold chain” nature of vaccine distribution. However the phenomenon of schedule divergence, where different vaccine products are now provided to segments of markets that used to share a single vaccine product, may threaten the use of tiered pricing.

Nowadays, compulsory licenses related explicitly to medicines are possible in most national legislation. A specific compulsory licence on a patented technology can be granted where the patent holder has abused his monopoly or where

it is otherwise in the public interest. Whether or not the necessary know-how is possessed by a potential compulsory licensee will impact the effectiveness of compulsory licensing, as too the effectiveness of patent waiving. However, the practical value of mandatory license provisions in the patent law is that of a powerful deterrent. Usually, the threat induces the grant of contractual licenses on reasonable terms. Thus the aim of actually manufacturing the patented invention is accomplished. Anyway, a notable precedent in the vaccine industry is the compulsory license granted in Israel in 1995 for the manufacturing of the DNA Hepatitis B vaccine covered by a Biogen patent (Cohn, 1997). In Australia, in at least two cases, the Trade Practices Act of 1974 was applied concerning incumbent monopolists' refusals to deal (O'Bryan, 1992); and two applications for compulsory licenses were reported in South Africa in 1993 (Sheppard, 1994).

Like any voluntary mechanism to increase R&D cooperation, C-TAP and Covax's success depend on the participation and direct collaboration of pharmaceutical MNCs, the sole legal owners of the patented technologies. At the end of April 2021, Covax shipped only one fifth of its projected estimates vaccines doses (see Erfani et al. 2021) and pharmaceutical MNCs have made no formal commitment to broad voluntary licensing schemes (de Menez, 2021). In this sense, the current TRIPS patent waiver framework seems to be at the moment the political and institutional response with the most significant potential to guarantee the scaling of the production of vaccines developed to fight Covid-19.

#### 4.1 A Model to Assess a Covid-19 Patent Waiver

Cozzi (2022) focussed on the following points covered by the recent debate on Covid-19 vaccines patent waiver:

1. A low probability of more firms producing Covid-19 vaccines in the case of a patent waiver;
2. A high expectation of a future patent waiver;
3. Government spending in R&D subsidy to keep R&D working.

Cozzi (2022) incorporated the previous points to draw conclusions about the desirability of a patent waiver. Paradoxically, it turns out that these three critical points raised against patent waivers turn out to be powerful arguments in favour of it.

While a patent suspension will increase future firm entry, it will also dissuade current R&D.

The mathematical outcome depends on the following three numbers:

1. The probability of new firms producing the vaccine if the government suspends the patent:  $p$ .
2. How many vaccine doses would the new entrant firms produce relative to monopolistic patent holder production:  $Q_E / Q_{NE}$ , where  $Q_{NE}$  is jabs

production in case of no entry, and  $Q_E > Q_{NE} > 0$  the jabs produced in case of competitive entry.

3. How much would the patent holder profits drop after competitive entry:  $V_{NE}/V_E$ , where  $V_E$  be the patent holder's profit in case of entry; and  $V_{NE} > V_E \geq 0$  be its profit in case of no entry.

The Cozzi (2022) shows that an expected patent waiver will increase the expected available vaccines if and only if the following inequality holds:

$$p \left( \frac{Q_E}{Q_{NE}} - 1 \right) + 1 > \frac{1}{p \left( \frac{V_E}{V_{NE}} - 1 \right) + 1}. \quad (1)$$

Under condition  $\frac{Q_E}{Q_{NE}} > 2 - \frac{V_E}{V_{NE}}$ , inequality (1) is equivalent to the following condition for the probability that after a waiver competitive firms will successfully enter the patented vaccine industry:

$$p \in \left( 0, \frac{\left( \frac{Q_E}{Q_{NE}} - 1 \right) + \left( \frac{V_E}{V_{NE}} - 1 \right)}{-\left( \frac{V_E}{V_{NE}} - 1 \right) \left( \frac{Q_E}{Q_{NE}} - 1 \right)} \right] \quad (2)$$

Therefore, the probability of imitators succeeding in copying the vaccine know-how cannot be high for the patent waiver to be beneficial.

In the case of Covid-19, it is widely believed that mRNA vaccines are very difficult to imitate because of the highly specialized know-how needed for their manufacturing. Interestingly, if this is true, the patent waiver will likely improve the expected future mRNA vaccines availability.

For example, assuming  $Q_E = 2Q_{NE}$  and  $V_E = 0.5V_{NE}$ , then (1) becomes:

$$p(2 - 1) + 1 > \frac{1}{p(0.5 - 1) + 1}.$$

that is:

$$0.5(1 - p)p > 0$$

which is satisfied for all  $p < 1$ .

Cozzi (2022) permits an evaluation of how much more R&D subsidies will be needed for the government to neutralize the disincentive effects of another expected waiver on the R&D for new vaccines. If the pre-waiver R&D subsidy rate is denoted  $s$ , after the waiver it will have to increase to

$$s^* = s_{NE} + \frac{V_{NE} - V_E}{V_{NE}} p (1 - s_{NE}). \quad (3)$$

With  $p = 0.10$  and  $V_E = 0.5V_{NE}$ , the increase in the subsidy rate needed to neutralize the patent waiver would be less 5%.

Hence, if the technological gap between the HICs' manufacturers, i.e. the technological incumbents and the LICs' outsiders, is high. Giving LICs a chance

to catch up by imitation with HICs' technology (by temporarily waiving the IPR) would not significantly affect the industry expected technological obsolescence. Therefore, with a small public subsidy paid to the vaccine developers proportionally to the R&D cost, the governments would re-optimize innovators' incentives in the next period. With a relatively small fiscal correction, governments could restore the intertemporal incentives to innovation provided by the IPR enforcement. Otherwise, the estimated benchmark global economic costs due to missing to vaccinate 50% of LICs' population is as high as \$3.8 trillion, of which 49% to pay by the same advanced economies through global value chain cascade effects (Çakmaklı et al. 2021).

## 5 Summary

Vaccines play a crucial role in improving global public health, with the ability to stem the spread of infectious diseases and the potential to eradicate them. However, the Covid-19 pandemic, with its enormous human and financial costs, suddenly reminded us of the precariousness of the human condition for the possible pathogenic events that nature can generate by itself.

The international epidemiological and economic, scientific community, along with international organizations and governments of developed and developing countries, repeatedly stated worries about the availability of Covid-19 vaccine doses in sufficient quantity and at affordable prices for the most vulnerable and marginalized populations in the world.

Several mutated SARS-CoV-2 viruses have already emerged, and variants can better evade vaccine-induced immune responses. Moreover, worldwide infection numbers have been climbing since February 2021 and coming in waves; by April 2021, case trajectories were growing exponentially in some places. Accordingly, lockdowns and NP interventions returned to be an option in several nations around the globe; and still, Covid-19 is on its way to becoming endemic.

Due to variants and waning immunity, specific vaccine boosters may be needed annually or every six months. In March 2022, China has started a strict lockdown in its Jilin province, despite nearly 90% of its population being vaccinated. The needed additional boosters could be on the order of 5 or 10 billion vaccinations a year, or over 10 or 20 billion doses for two-dose vaccines, to be equitably and effectively distributed all over the world. Unless governments guarantee the scaling of the global vaccines production to allow timely, sufficient, and affordable access to all preventive technologies developed against Covid-19; SARS-CoV-2 is likely to continue circulating and evolving around the globe as an endemic disease (i.e. with epidemic cycles), possibly with medium-sized acute epidemic episodes (Goenka, Liu and Nguyen, 2021).

Although the existing viral strains arose separately, they have commonalities represented by changes in specific sites of the spike protein, likely because of similar selective pressures, e.g., increasing immunity (Caldwel et al., 2021). Through natural evolution, SARS-CoV-2 will likely continue spreading and shift to primary infection among younger age groups (Lavine et al. 2021; Caldwell et



al. 2021); with possible devastating long-term consequences for the economies of the developing countries due to demographic reasons (see Tables 1.A and 1.B in Appendix; Musa et al. 2020; and Coker et al. 2021). And for the world economy as a whole (Çakmaklı et al. 2021).

The international scientific community amply supported the proposal of a temporary patent waiver for Covid-19 vaccines as a tool to increase global supply, achieve global herd immunity, and advance global health equity. However, without vaccine manufacturing liberalization, there will not be jabs fast enough to prevent the spread of SARS-Cov2 variants, the avoidable deaths, and the continuing choking of low and middle-income countries through poor health (Erfani et al., 2021; among others), with enormous consequences also for the advanced economies.

At the same time, innovation must be globally rewarded. Although sometimes hardly criticized (see Kremer and Williams, 2010; Pagano and Rossi, 2011; Belloc and Pagano, 2012; Boldrin and Levine, 2013; among others), the global implementation of a modern IPR system happened during the middle 1990's, when many developing countries joined the WTO. The TRIPS provided the right legal instrument and appropriate economic incentive to support innovation and technological development worldwide. By allowing mainly middle-income economies to shift from imitation-intensive production regimes into knowledge-intensive productions - characterized by domestic innovation with well-designed and adequately enforced IPR laws (see Banerjee and Nayak, 2014; among others). Since then, the predominant mode of private R&D incentivization has been through-out IPR and the TRIPS Agreement. The monopoly power granted by globally enforced patents earned innovative MNCs sufficient profit to repay R&D. At the same time, the bulk of basic research in HICs keeps being financed or directly carried-out by public sector institutions, which traditionally pair with private R&D firms to develop their scientific knowledge into viable products (see Akcigit et al., 2021; among others).

This chapter showed that the governments can take an active role in supporting private R&D on new and better vaccines, while at the same time promoting the know-how transfer needed to guarantee a production booster and reach world herd immunity. Therefore, overcoming knowledge transfer impediments, including those operating via IPRs, will be crucial to defeat the Covid-19 pandemics. The insights of this chapter will be also helpful for other pandemics.

### **Aknowledgement**

Responsible Section Editor: Sergio Scicchitano

The article has benefitted from valuable comments of the editors and anonymous referees. There is no conflict of interest.

## 6 References

### References

- [1] Acemoglu D., V. Chernozhukov, I. Werning and M.D. Whinston (2021). "Optimal Targeted Lockdowns in a Multi-Group SIR Model", *American Economic Review: Insights* 3(4), pp. 487-502.
- [2] Agarwal R. and T. Reed (2021) "How to End the COVID-19 Pandemic by March 2022", World Bank Group, April, 2021, Policy Research Working Paper 9632.
- [3] Aghion P. and P. Howitt (1996). "Research and Development in the Growth Process". *Journal of Economic Growth*, Vol. 1, No. 1 (Mar., 1996), pp. 49-73.
- [4] Agostinelli F., M. Doepke, G. Sorrenti, and F. Zilibotti (2022). "When the great equalizer shuts down: Schools, peers, and parents in pandemic times. *Journal of Public Economics*. 2022 Feb; 206:104574.
- [5] Akcigit U., D. Hanley and N. Serrano-Velarde (2021). "Back to Basics: Basic Research Spillovers, Innovation Policy, and Growth," *Review of Economic Studies*, Oxford University Press, vol. 88(1), pages 1-43.
- [6] Alimohamadi Y., M. Taghdir and M. Sepandi (2020). "Estimate of the basic reproduction number for COVID-19: A systematic review and meta-Analysis". *Journal of Preventive Medicine and Public Health*, Korean Society Preventive Medicine; 2020; 53:151–7. Available from: /pmc/ articles/PMC7280807/.
- [7] Annemans L., P. Beutels, D.E. Bloom, et al. (2021). "Economic evaluation of vaccines: Belgian reflections on the need for a broader perspective". *Value Health*. 24(1):105–111.
- [8] Augustin E. (2022). "Cuba's vaccine success story sails past mark set by rich world's Covid efforts", *The Guardian*, Wed 5 Jan 2022 10.00 GMT, <https://www.theguardian.com/world/2022/jan/05/cuba-coronavirus-covid-vaccines-success-story>. Accessed 1, Feb. 2022.
- [9] Banerjee T. and A. Nayak (2014). "Effects of Trade Related Intellectual Property Rights on the research and development expenditure of Indian pharmaceutical industry". *Journal of Pharmaceutical Health Services Research*. 5 (2): 89–94. doi:10.1111/jphs.12050. S2CID 70896207.
- [10] Bärnighausen T, D.E. Bloom, E.T. Cafiero-Fonseca, and J.C. O'Brien (2014). "Valuing vaccination". *Proceedings of the National Academy of Sciences USA*. 2014;111.

- [11] BBC (2020). "Coronavirus: US buys nearly all of Gilead's Covid-19 drug remdesivir". <https://www.bbc.co.uk/news/world-us-canada-53254487> (accessed Jan 24, 2020).
- [12] Belloc F and U. Pagano (2013). "Knowledge Enclosures, Forced Specializations and Investment Crisis". *The European Journal of Comparative Economics* Vol. 9, n. 3, pp. 445-483 ISSN 1722-4667
- [13] Betsch C., R. Bohm and L. Korn (2013), "Inviting free-riders or appealing to prosocial behavior? Game-theoretical reflections on communicating herd immunity in vaccine advocacy", *Health Psychology* 32(9): 978–985.
- [14] Beutels P., E. Van Doorslaer, P. Van Damme, and J. Hall (2003). "Methodological issues and new developments in the economic evaluation of vaccines". *Expert Review Vaccines*. 2003; 2(5): 649–660.
- [15] Beutels P., W.J. Edmunds, and R.D. Smith (2008). "Partially wrong? Partial equilibrium and the economic analysis of public health emergencies of international concern". *Health Economics*; 17(11): 1317–1322.
- [16] Beutels P., N. Jia, Q. Y. Zhou et al. (2009). "The economic impact of SARS in Beijing, China". *Tropical Medicine and International Health*. 2009; 14 (suppl 1):85–91.
- [17] Beutels P., P. A. Scuffham, and C.R. MacIntyre (2008). "Funding of drugs: do vaccines warrant a different approach?" *The Lancet Infectious Diseases*. 2008;8(11):727–733.
- [18] Bilcke J. and P. Beutels (2009). "Reviewing the cost effectiveness of rotavirus vaccination: the importance of uncertainty in the choice of data sources". *Pharmacoeconomics*, 2009; 27:281-97; PMID:19485425; <http://dx.doi.org/10.2165/00019053-200927040-00002>.
- [19] Bilcke J., S. Coenen, and P. Beutels (2014). "Influenza-like-illness and clinically diagnosed flu: disease burden, costs and quality of life for patients seeking ambulatory care or no professional care at all". *PLoS One*. 2014;9(7):e102634.
- [20] Bilcke J., P. Van Damme and P. Beutels (2009). "Cost-effectiveness of rotavirus vaccination: exploring caregiver(s) and "no medical care" disease impact in Belgium". *Medical Decision Making* 2009; 29:33-50.
- [21] Blanchard-Rohner G., B. Caprettini, D. Rohner, H.J. Voth (2021), "From tragedy to hesitancy: How public health failures boosted COVID-19 vaccine scepticism", VoxEU.org, 01 June.
- [22] Boersma, C. and Postma, M. J. (2021). "Health Economics of Vaccines: From Current Practice to Future Perspectives". *Value in Health*, 24(1), 1-2. <https://doi.org/10.1016/j.jval.2020.11.006>.

- [23] Boldrin M. and D.K. Levine (2013). "The Case against Patents". *Journal of Economic Perspectives*, Vol. 27, No. 1, Winter (pp. 3-22)
- [24] Bos J.M., P. Beutels, L. Annemans, and M.J. Postma. (2004). "Valuing prevention through economic evaluation". *Pharmacoeconomics*. 2004;22(18):1171-1179.
- [25] Boucekkine R., A. Carvajal, S. Chakraborty and A. Goenka (2021). "The economics of epidemics and contagious diseases: An introduction," Post-Print hal-03164713, HAL.
- [26] Boucekkine R., S. Chakraborty and A. Goenka (2021). "The economics of epidemics and emerging diseases", *Journal of Mathematical Economics*. Special issues on Post-Print hal-03164742, HAL.
- [27] Braithwaite J. and P. Drahos (2000). "Global Business Regulation", Cambridge University Press. Freely downloadable at <http://johnbraithwaite.com/wp-content/uploads/2016/06/Global-Business-Regulation.pdf>
- [28] Brooks-Pollock E., H. Christensen, A. Tricke, G. Hemani, E. Nixon and A. Thomas, et al. (2020). "High COVID-19 transmission potential associated with re-opening universities can be mitigated with layered interventions". *medRxiv*. 2020; Available from: <https://doi.org/10.1101/2020.09.10.20189696>.
- [29] Bukhari N., M. Manzoor, and H. Rasheed (2020). "A step towards gender equity to strengthen the pharmaceutical workforce during COVID-19". *Journal of Pharmaceutical Policy and Practice* 13, 15 (2020). <https://doi.org/10.1186/s40545-020-00215-5>.
- [30] Çakmaklı C., S. Demiralp, S. Kalemli-Özcan, S. Yeşiltaş and M. A. Yıldırım (2021), "The Economic Case for Global Vaccinations: An Epidemiological Model with International Production Networks", NBER WORKING PAPER 28395, DOI 10.3386/w28395, revised April 2021.
- [31] Caldwell JM, Le X, McIntosh L, Meehan MT, Ogunlade S, Ragonnet R, O'Neill GK, Trauer JM, McBryde ES (2021). "Vaccines and variants: Modelling insights into emerging issues in COVID-19 epidemiology". *Paediatr Respir Rev*. 2021 Sep;39:32-39. doi: 10.1016/j.prrv.2021.07.002. Epub 2021 Jul 21. PMID: 34417121; PMCID: PMC8294600.
- [32] Chang-Monteagudo A., R. Ochoa-Azpe, Y. Climent-Ruiz, C. Macías-Abraham, L. Rodríguez-Noda, C. Valenzuela-Silva, B. Sánchez-Ramírez, R. Perez-Nicado, T. Hernández-García, et al. (2021). "A single dose of SARS-CoV-2 FINLAY-FR-1A vaccine enhances neutralization response in COVID-19 convalescents, with a very good safety profile: An open-label phase 1 clinical trial". *The Lancet Regional Health - Americas*, Volume 4, 2021, 100079, ISSN 2667-193X, <https://doi.org/10.1016/j.lana.2021.100079>.

- [33] Chaudhuri S. (2020). "Making Covid-19 Medical Products Affordable: Voluntary Patent Pool and TRIPS Flexibilities". SouthViews No. 200.
- [34] Chetty R., J. Friedman, N. Hendren, M. Stepner, and the Opportunity Insights Team (2020), "The Economic Impacts of COVID-19: Evidence from a New Public Database Built Using Private Sector Data", NBER Working Paper No. 26463 (November 2020).
- [35] Chinazzi M., J. T. Davis, N. E. Dean, K. Mu, A. Pastore y Piontti, X. Xiong, et al.(2020). "Estimating the effect of cooperative versus uncooperative strategies of COVID 19 vaccine allocation: a modeling study". Available from: <https://www.networkscienceinstitute.org/publications/estimating-the-effect-of-cooperative-versus-uncooperative-strategies-of-covid-19-vaccine-allocation-a-modeling-study>
- [36] Chu A., G. Cozzi and S. Galli (2012). "Does intellectual monopoly stimulate or stifle innovation?" *European Economic Review*, Elsevier, vol. 56(4), pages 727-746.
- [37] Chu A., G. Cozzi and S. Galli (2014). "Stage-dependent intellectual property rights". *Journal of Development Economics*, 106 (January 2014). 239-249. ISSN 0304-3878
- [38] Coker M., M.O. Folayan, I.C. Michelow, R.E. Oladokun, N. Torbunde and N.A. Sam-Agudu (2021) "Things must not fall apart: the ripple effects of the COVID-19 pandemic on children in sub-Saharan Africa". *Pediatric Research*. 2021 Apr;89(5):1078-1086. doi: 10.1038/s41390-020-01174-y. Epub 2020 Sep 24. PMID: 32971527; PMCID: PMC8119239.
- [39] Cohn M (1997). "Compulsory licence for the manufacture of a Hepatitis B Vaccine: exploitation of the invention for R&D prior to compulsory licence proceedings in Israel". *Patent World*, 96, 27-29.
- [40] Connolly M.P., Topachevskiy O., Standaert B., Ortega O., and M. Postma (2012). "The impact of rotavirus vaccination on discounted net tax revenue in Egypt: a government perspective analysis". *Pharmacoeconomics*. 2012; 30(8): 681–695.
- [41] Costa-Font J. and S Machado (2021), "How can policy interventions encourage pro-social behaviours in the health system?", LSE Public Policy Review 1(3).
- [42] Costa-Font J., C. Rudisill, S. Harrison and L Salmasi (2021), "The Social Value of a SARS-CoV-2 Vaccine: Willingness to Pay Estimates from Four Western Countries", *IZA Working Paper* 14475.
- [43] Cozzi G. (2022). "Shall we fear a Patent Waiver? Not for Covid-19", [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=4015067](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4015067).

- [44] Cozzi G. and M. Davenport (2017). "Extrapolative expectations and capital flows during convergence," *Journal of International Economics*, Elsevier, vol. 108(C), pages 169-190.
- [45] Cozzi G. and S. Galli (2014). "Sequential R&D and blocking patents in the dynamics of growth". *J Econ Growth* 19, 183–219 (2014). <https://doi.org/10.1007/s10887-013-9101-5>
- [46] Cozzi G. and S. Galli (2017) "Should the Government Protect its Basic Research?" *Economics Letters*, 157 122-124. ISSN 0165-1765
- [47] Cozzi G. and S. Galli (2021). "Privatization of knowledge: Did the U.S. get it right?" *Economic Modelling*, Volume 98, 2021, Pages 179-191, SSN 0264-9993, <https://doi.org/10.1016/j.econmod.2021.01.011>.
- [48] Cozzi G., S. Galli and M. Iordache-Bolboaca (2018). "Medium Frequencies in Non-Frontier Economies", *Economics Working Paper Series* 255917, University of St. Gallen, School of Economics and Political Science.
- [49] Dagan N., N. Barda, E. Kepten, O. Miron, S. Perchik, M. A. Katz, M. A. Hernán, M. Lipsitch, B. Reis and R. D. Balicer (2021), "BNT162b2 mRNA Covid-19 Vaccine in a Nationwide Mass Vaccination Setting", *New England Journal of Medicine* 15 April.
- [50] Davies N.G., S. Abbott, R.C. Barnard RC, C.I. Jarvis, A.J. Kucharski, J.D. Munday, et al. (2021). "Estimated transmissibility and impact of SARS-CoV-2 lineage B.1.1.7 in England". *Science* (80-) 2021; 372(6538): eabg3055. [https://doi.org/10.1126/science:abg3055](https://doi.org/10.1126/science.abg3055)
- [51] Deb, P., D. Furceri, D. Jimenez, D. et al. (2022) "The effects of COVID-19 vaccines on economic activity". *Swiss J Economics Statistics* 158, 3 (2022). <https://doi.org/10.1186/s41937-021-00082-0>
- [52] de Menez E.Z. (2021). "The TRIPS Waiver Proposal: an Urgent Measure to Expand Access on the COVID-19 Vaccines", The South Centre, Geneva, Research Paper 129.
- [53] Dewatripont M. (2021), "Vaccination strategies in the midst of an epidemic", CEPR Policy Insight No 110.
- [54] Doepke M. and M. Tertilt (2019). "Does Female Empowerment Promote Economic Development?". *Journal of Economic Growth*, December 2019.
- [55] Edward-Ekpu U. (2021). "Egypt races to produce critically-needed covid-19 vaccines". *Quartz Africa* 2021 Jun 11. <https://qz.com/africa/2019420/egypt-races-to-produce-critically-needed-covid-19-vaccines/>
- [56] Erfani P, Binagwaho A, Jalloh M J, Yumus M, Farmer P, Kerry V et al. Intellectual property waiver for covid-19 vaccines will advance global health equity *BMJ* 2021; 374 :n1837 doi:10.1136/bmj.n1837

- [57] Figueiredo A., C. Simas, E. Karafillakis, P. Paterson and H. J. Larson (2020), "Mapping global trends in vaccine confidence and investigating barriers to vaccine uptake: a large-scale retrospective temporal modelling study", *The Lancet* 396(10255): 898–908.
- [58] Finger J.M. (2000). "The WTO's special burden on less developed countries", *Cato Journal* 19 (3).
- [59] Forslide, R. and M. Herzing, (2015), "On the optimal production capacity for influenza vaccine", *Health Economics*, ;24(6), pp.726-41.
- [60] Forslide, R. and M. Herzing, (2021), "Who to vaccinate first: Some important trade-offs", *Covid Economics* 79, 2021, pp. 93-116.
- [61] Garrison C. (2004). "Intellectual Property Rights and Vaccines in Developing countries", background paper for the purpose of the WHO meeting IP and Vaccines, held in Geneva 19th-20th April 2004.
- [62] Gersbach H., U. Schetter, and S. Schmassmann (2018). "From Local to Global: A Unified Theory of Public Basic Research," *Economics Working Paper Series* 1816, University of St. Gallen, School of Economics and Political Science.
- [63] Gersbach H., G. Sorger and C. Amon (2018). "Hierarchical growth: Basic and applied research," *Journal of Economic Dynamics and Control*, Elsevier, vol. 90(C), pages 434-459.
- [64] Goenka A. (2021), "The Economics of Epidemics and Contagious Diseases: an Introduction", *Journal of Mathematical Economics*. 93, 8 p., 102498.
- [65] Goenka A. and L. Liu (2013), "Infectious Diseases and Endogenous Fluctuations", *Economic Theory*, 125-149.
- [66] Goenka A. and L. Liu (2020), "Human Capital, Infectious Diseases and Economic Growth", *Economic Theory*, 70, 1-47.
- [67] Goenka A., L. Liu and M.H. Nguyen (2014), "Infectious Diseases and Economic Growth", *Journal of Mathematical Economics* 50, 34-53.
- [68] Goenka A., L. Liu and M.H. Nguyen (2021), "SIR Economic Epidemiological Models with Disease Induced Mortality", *Journal of Mathematical Economics*, 2021, 93.
- [69] Gomes M.G.M., G.F. Medley and D.J. Nokes (2002). "On the determinants of population structure in antigenically diverse pathogens". *Proceedings of the Royal Society B: Biological Sciences* 2002; 269 (1488):227–33. Available from: <https://royalsocietypublishing.org/>.
- [70] Green J. R., and S. Scotchmer (1995). "On the Division of Profit in Sequential Innovation". *The RAND Journal of Economics*, 26(1), 20–33. <https://doi.org/10.2307/2556033>

- [71] Gu Y., E. Lancsar, P. Ghijben, J.R. Butler and C. Donaldson (2015). "Attributes and weights in health care priority setting: a systematic review of what counts and to what extent". *Social Science & Medicine*. 2015; 146: 41–52.
- [72] Gupta S., N. Ferguson and R. Anderson (1998). "Chaos, Persistence, and Evolution of Strain Structure in Antigenically Diverse Infectious Agents". *Science* (80). 1998; 280 (5365):912 LP – 915.
- [73] Gurry F. (2020), "Some Considerations on Intellectual Property, Innovation, Access and COVID-19", Statement of the World Intellectual Property Organization (WIPO) General Director.
- [74] Gurwitz D. ( 2021). "Ethical tradeoffs in SARS-CoV-2 vaccine development: Assuring fair availability for low-income countries". *Vaccines*, 39 (2021) 1027.
- [75] Hall V. J., S. Foulkes, A. Saei, N. Andrews, B. Oguti, A. Charlett, E. Wellington, J. Stowe, N. Gillson, A. Atti and J. Islam (2021), "COVID-19 vaccine coverage in health-care workers in England and effectiveness of BNT162b2 mRNA vaccine against infection (SIREN): a prospective, multicentre, cohort study", *The Lancet* 397(10286): 1725–35.
- [76] Head M. (2021). "Cuba's COVID vaccines: the limited data available suggests they're highly effective", *The Conversation*, December 7, 2021: accessed on January 27, 2022 at <https://theconversation.com/cubas-covid-vaccines-the-limited-data-available-suggests-theyre-highly-effective-172725>
- [77] Head J.R.,K. Andrejko, Q. Cheng, P.A. Collender, S. Phillips, A. Boser, et al. (2020). "The effect of school closures and reopening strategies on COVID-19 infection dynamics in the San Francisco Bay Area: a cross-sectional survey and modeling analysis"..*medRxiv Preprint Service for Health Sciences*. 2020;2020.08.06.20169797. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/32793934>
- [78] Heinemann A. (2019). "Blocking Patents and the Process of Innovation". In: Mathis K., Tor A. (eds) *New Developments in Competition Law and Economics. Economic Analysis of Law in European Legal Scholarship*, vol 7. Springer, Cham. [https://doi.org/10.1007/978-3-030-11611-8\\_8](https://doi.org/10.1007/978-3-030-11611-8_8)
- [79] Hogan A.B., P. Winskill, O.J. Watson, P.G.T. Walker, C. Whittaker, M. Baguelin, et al. (2021). "Within-country age-based prioritisation, global allocation, and public health impact of a vaccine against SARS-CoV-2: A mathematical modelling analysis". *Vaccine* 2021;39(22):2995–3006.
- [80] Irwin A.(2021). "What it will take to vaccinate the world against covid-19". *Nature* 2021;592:176-8.



- [81] Jarvis L.M. (2018). "Why can't the drug industry solve its gender diversity problem?", *Chemical and Engineering News*, Volume 96 Issue 10.
- [82] Jerving S. (2021). "Biovac Institute to be first African company to produce mRNA vaccines". *Devex* 2021 Jul 21. <https://www.devex.com/news/biovac-institute-to-be-first-african-company-to-produce-mrna-vaccines-100432>
- [83] Jit M. and W.J. Edmunds (2007). "Evaluating rotavirus vaccination in England and Wales. Part II. The potential cost-effectiveness of vaccination". *Vaccine* 2007; 25:3971-9.
- [84] Jones C., T. Philippon and V. Venkateswaran (2021). "Optimal Mitigation Policies in a Pandemic: Social Distancing and Working from Home", *The Review of Financial Studies*, Volume 34, Issue 11, November 2021, Pages 5188–5223, <https://doi.org/10.1093/rfs/hhab076>
- [85] Karatayev V.A., M. Anand and C.T. Bauch (2020). "Local lockdowns outperform global lockdown on the far side of the COVID-19 epidemic curve". *Proc Natl Acad Sci U S A* 2020;117(39):24575–80. Available from: [www.pnas.org/cgi/doi/10.1073/pnas.2014385117](http://www.pnas.org/cgi/doi/10.1073/pnas.2014385117).
- [86] Keeling M.J. and P. Rohani (2008). "Modeling infectious diseases in humans and animals." Princeton University Press; 2008. Available online from: <http://www.jstor.org/stable/j.ctvcn4gk0>
- [87] Keogh-Brown M.R. and R.D. Smith RD (2008). "The economic impact of SARS: how does the reality match the predictions?" *Health Policy*. 2008;88(1):110–120.
- [88] Keogh-Brown M.R., R.D. Smith, J.W. Edmunds and P. Beutels (2010). "The macroeconomic impact of pandemic influenza: estimates from models of the United Kingdom, France, Belgium and the Netherlands". *The European Journal of Health Economics*. 2010;11(6): 543–554.
- [89] Keynes J.M. (1936). "The General Theory of Employment, Interest and Money", MacMillan and Co., London.
- [90] Kiedaisch C. (2015). "Intellectual Property Rights in a Quality-Ladder Model with Persistent Leadership", *European Economic Review*, Vol. 80, 194-213
- [91] Kis, Z., Kontoravdi, C., Dey, A.K., Shattock, R. and Shah, N. (2020a), "Rapid development and deployment of high-volume vaccines for pandemic response". *J Adv Manuf Process*, 2: e10060. <https://doi.org/10.1002/amp2.10060>
- [92] Kis, Z., Kontoravdi, C., Shattock, R., & Shah, N. (2020b). "Resources, Production Scales and Time Required for Producing RNA Vaccines for the Global Pandemic Demand. *Vaccines*, 9(1), 3. <https://doi.org/10.3390/vaccines9010003>

- [93] Kotsopoulos N., M.P. Connolly, V. Remy (2015). "Quantifying the broader economic consequences of quadrivalent human papillomavirus (HPV) vaccination in Germany applying a government perspective framework. *Health Economics Review*. 2015; 5(1): 54.
- [94] Lamy P. (2020), "On the production of and equitable access to COVID-19 tests, treatments, and vaccines", VoxEU.org, 06 November.
- [95] Lyngse F. P., C. T. Kirkeby, M. Denwood, L.E. Christiansen, K. Mølbak, C. Holten Møller, R. L. Skov, T. Grove Krause, M. Rasmussen, R. N. Sieber, T. B. Johannesen, T. Lillebaek, J. Fonager, A. Fomsgaard, F. T. Møller, M. Stegger, M. Overvad, K. Spiess and L.H. Mortensen (2022). "Transmission of SARS-CoV-2 Omicron VOC subvariants BA.1 and BA.2: Evidence from Danish Households", *medRxiv* 2022.01.28.22270044; doi: <https://doi.org/10.1101/2022.01.28.22270044>
- [96] Lobo F. (2021). "Restructuring the Global Vaccine Industry", *The South Centre, working paper 134*, Geneva: September 2021.
- [97] Luyten J., V. Dorgali, N. Hens and P. Beutels (2013). "Public preferences over efficiency, equity and autonomy in vaccination policy: an empirical study". *Social Science & Medicine*. 2013;77:84–89.
- [98] Luyten J., R. Kessels, P. Goos and P. Beutels (2015). "Public preferences for prioritizing preventive and curative health care interventions: a discrete choice experiment". *Value Health*. 2015;18(2): 224–233.
- [99] Luyten J., B. Ogunjimi and P. Beutels (2014). "Varicella-zoster virus vaccination under the exogenous boosting hypothesis: two ethical perspectives". *Vaccine*. 2014;32(52): 7175–7178.
- [100] Mahase E. (2021). "Covid-19: Do vaccines work against omicron—and other questions answered". *BMJ* 2021; 375 :n3062 doi:10.1136/bmj.n3062
- [101] Marriot A. and A. Maitland (2021). "The Great Vaccine Robbery", *The People's Vaccine Policy Brief*, [https://webassets.oxfamamerica.org/media/documents/The\\_Great\\_Vaccine\\_Robbery\\_Policy\\_Brief.pdf](https://webassets.oxfamamerica.org/media/documents/The_Great_Vaccine_Robbery_Policy_Brief.pdf)
- [102] Martinez-Bravo M. and A. Stegmann (2021). "In Vaccines We Trust? The Effects of the CIA's Vaccine Ruse on Immunization in Pakistan." *Journal of the European Economic Association*, 2021;, jvab018, <https://doi.org/10.1093/jea/jvab018>
- [103] McBryde E.S., J.M. Trauer, A. Adekunle, R. Ragonnet and M.T. Meehan (2020). "Stepping out of lockdown should start with school re-openings while maintaining distancing measures. Insights from mixing matrices and mathematical models" *medRxiv*. 2020;2020.05.12.20099036.

- [104] Médecins Sans Frontières (2020). "WTO covid-19 TRIPS waiver proposal". [https://msfaccess.org/sites/default/files/2020-12/MSF-AC\\_COVID\\_IP\\_TRIPSWaiverMythsRealities\\_Dec2020.pdf](https://msfaccess.org/sites/default/files/2020-12/MSF-AC_COVID_IP_TRIPSWaiverMythsRealities_Dec2020.pdf)
- [105] Meredith S. (2022). "Why Cuba's extraordinary Covid vaccine success could provide the best hope for low-income countries", CNBC Health and Science, Published on JAN 13 2022; accessed on JAN 23 2022 <https://www.cnbc.com/2022/01/13/why-cubas-extraordinary-covid-vaccine-success-could-provide-the-best-hope-for-the-global-south.html>
- [106] Morin J.-F. and M. Bourassa Forcier (2011). "Pharmaceutical Patent Policy in Developing Countries: Learning from the Canadian Experience," Chapters, in: Kenneth C. Shadlen & Samira Guennif & Alenka Guzmán & Narayanan Lalitha (ed.), Intellectual Property, Pharmaceuticals and Public Health, chapter 8, Edward Elgar Publishing.
- [107] Morten C. and M. Herder (2021). "We can't trust big pharma to make enough vaccines". *Nation* 2021 May 31. <https://www.thenation.com/article/world/covid-vaccines-pharma/>
- [108] Munoz Tellez V. (2020). "The COVID-19 Pandemic: R&D and Intellectual Property Management for Access to Diagnostics, Medicines and Vaccines". *South Centre Policy Brief* No. 73.
- [109] Musa S.S., S. Zhao, M.H. Wang, A.G. Habib, U.T. Mustapha and D. He (2020). "Estimation of exponential growth rate and basic reproduction number of the coronavirus disease 2019 (COVID-19) in Africa". *Infectious Diseases of Poverty*. 2020; 9(1):1–6.
- [110] Muscatelli A., (2020), "Paying for Coronavirus Will Have to be like War Debt – Spread over Generations", *The Conversation*, June 11, 2020.
- [111] Musungu S.F. and C. Oh (2005), "The use of flexibilities in TRIPS by developing countries: can they promote access to medicines?", Commission on Intellectual Property Rights, Innovation and Public Health (CIPIH), WHO.
- [112] Namboodiri S. (2020). "COVID-19: An Opportunity to Fix Dysfunctional Biomedical R&D System". *South Views* No. 195.
- [113] Nature (2021). "A patent waiver on COVID vaccines is right and fair", Editorial 27 May 2021.
- [114] O'Bryan M. (1992). "Refusal to license intellectual property under the Australian Trade Practices Act". *Patent World*, 42, 10-14.
- [115] Oxfam (2021). "Pfizer, BioNTech and Moderna making \$1,000 profit every second while world's poorest countries remain largely unvaccinated", <https://www.oxfam.org/en/press-releases/pfizer-biontech-and-moderna-making-1000-profit-every-second-while-worlds-poorest>. Accessed 30 Januar 2022.

- [116] Pagano U. and M.A. Rossi (2009). "The Crash of the Knowledge Economy". *Cambridge Journal of Economics*, Vol. 33, Issue 4, pp. 665-683, 2009, Available at SSRN: <https://ssrn.com/abstract=1433951> or <http://dx.doi.org/10.1093/cje/bep033>
- [117] Pardi N., M. Hogan, F. Porte et al. (2018) "mRNA vaccines - a new era in vaccinology". *Nature Reviews Drug Discovery* 17, 261–279 (2018). <https://doi.org/10.1038/nrd.2017.243>
- [118] Park A. and A. Baker (2021). "Exclusive: Inside the Facilities Making the World's Most Prevalent COVID-19 Vaccine". The Times, April 19th 2021, <https://time.com/5955247/inside-biontech-vaccine-facility/> accessed on March 24th 2022.
- [119] Postma, M. J., and B.A. Standaert (2013). "Economics of vaccines revisited". *Human vaccines & immunotherapeutics*, 9(5).
- [120] Prager F., D. Wei and A. Rose (2017). "Total economic consequences of an influenza outbreak in the United States". *Risk Analysis*. 2017; 37(1): 4–19.
- [121] Reardon S. (2021). "Cuba's bet on home-grown COVID vaccines is paying off", *Nature*, 600, 15-16 (2021) doi: <https://doi.org/10.1038/d41586-021-03470-x>
- [122] Reuters (2021), 29 Dec, 2021, "Cuba to fast-track boosters as Omicron looms", <https://www.reuters.com/world/americas/cuba-fast-track-boosters-omicron-looms-2021-12-29/> (accessed Jan 27, 2022).
- [123] Reuters (2022). "Exclusive: Senegal expects 400,000 COVID-19 vaccines to expire by year-end". <https://www.reuters.com/business/healthcare-pharmaceuticals/exclusive-senegal-expects-waste-400000-covid-19-vaccines-by-year-end-2021-12-13/>
- [124] Rozenbaum M.H., M.J.Mangen, C. Giaquinto, J.C. Wilschut, E. Hak and M.J. Postma (2011). "Consensus Group on Dutch Rotavirus Vaccination (CoRoVa-Group). Cost-effectiveness of rotavirus vaccination in the Netherlands; the results of a consensus model. *BMC Public Health* 2011; 11:462; PMID:21663620.
- [125] Russell F.M. and B. Greenwood (2020). "Who should be prioritised for COVID-19 vaccination?". *Human Vaccines & Immunotherapeutics* 2020:1–5.
- [126] Scotchmer S. (2004). "Innovation and Incentives", MIT Press.
- [127] Sell S.K. (2003). "Private Power, Public Law: The Globalization of Intellectual Property Rights". Cambridge University Press. doi:10.1017/cbo9780511491665. ISBN 978-0-521-81914-5.

- [128] Sheppard D. (1994). "Compulsory licences in South Africa". *Patent World*, 59, 23-28.
- [129] Smith A. (1776). "An Inquiry into the Nature and Causes of the Wealth of Nations." re-published in 2008 by OUP, Oxford, 2008.
- [130] Smith R.D., M.R. Keogh-Brown, T. Barnett and J. Tait (2009). "The economy-wide impact of pandemic influenza on the UK: a computable general equilibrium modelling experiment". *The British Medical Journal BMJ*. 2009;339:b4571.
- [131] Smith R.D., M. Yago, M. Millar and J. Coast (2005). "Assessing the macroeconomic impact of a healthcare problem: the application of computable general equilibrium analysis to antimicrobial resistance". *Journal of Health Economics*. 2005;24(6):1055–1075.
- [132] Standaert B., N. Parez, B. Tehard, X. Colin, and B. Detournay (2008); "Cost-effectiveness analysis of vaccination against rotavirus with RIX4414 in France". *Applied Health Economics and Health Policy* 2008; 6:199-216; PMID:19382820; <http://dx.doi.org/10.1007/BF03256134>.
- [133] Standaert B., C. Sauboin, R. DeAntonio R, et al. (2020). "How to assess for the full economic value of vaccines? From past to present, drawing lessons for the future". *J Mark Access Health Policy*. 2020;8(1):1719588.
- [134] Stone J. (2020) "Government says medicines must be stock-piled for no-deal Brexit on top of Covid-19 pressures." Independent. 3 Aug 2020. <https://www.independent.co.uk/news/uk/politics/coronavirus-no-deal-brexit-government-medicine-stockpiling-a9651991.html> (accessed Jan 27, 2022).
- [135] Syam N. (2020), "Intellectual Property, Innovation and Access to Health Products for COVID-19: A Review of Measures Taken by Different Countries". The South Centre Policy Brief 80, June 2020.
- [136] Taylor L. (2021). "Cuba's home-grown vaccines have massively cut covid-19 cases". *New Scientist* 2021 Dec 23. <https://www.newscientist.com/article/2303121-cubas-home-grown-vaccines-have-massively-cut-covid-19-cases/>
- [137] Thambisetty S., A. McMahon, L. McDonagh, H.Y. Kang and G. Dutfeld (2021). "The TRIPS Intellectual Property Waiver Proposal: Creating the Right Incentives in Patent Law and Politics to end the COVID-19 Pandemic" (May 24, 2021). *LSE Legal Studies Working Paper* No. 06/2021, Available at SSRN: <https://ssrn.com/abstract=3851737> or <http://dx.doi.org/10.2139/ssrn.3851737>
- [138] Toledo-Romani M.E., M. Garcia-Carmenate, C. Valenzuela Silva, W. Baldoquin-Rodriguez, M. Martínez Pérez, M. C. Rodríguez Gonzalez,

- B. Paredes Moreno, I. C. Mendoza Hernández, and the SOBERANA Phase 3 team (2021). "Efficacy and safety of SOBERANA 02, a COVID-19 conjugate vaccine in heterologous three-dose combination", *medRxiv* 2021.10.31.21265703; doi: <https://doi.org/10.1101/2021.10.31.21265703>
- [139] Yang Y. (2018). "On the Optimality of IPR Protection with Blocking Patents," *Review of Economic Dynamics*, vol. 27, pages 205-230, January.
- [140] Wallace K. (2019). "The diversity imperative in pharma", *The Pharmaletter*: <https://www.thepharmaletter.com/article/the-diversity-imperative-in-pharma>
- [141] Watal J. (2001). "Intellectual Property Rights in the WTO and Developing Countries", Kluwer Law International.
- [142] Wen E P., Ellis R J , and Pujar N S.( 2015). "Vaccine Development and Manufacturing", Wiley Series in Biotechnology and Bioengineering (Hoboken, New Jersey, United States: John Wiley & Sons, Inc., 2015).
- [143] Westra T.A., M. Parouty, W.B. Brouwer, et al. (2012). "On discounting of health gains from human papillomavirus vaccination: effects of different approaches". *Value Health*. 2012;15(3):562–567.
- [144] WHO Coronavirus (COVID-19) Dashboard. <https://covid19.who.int/>. Accessed 20 Jan 2022.
- [145] WHO SAGE values framework for the allocation and prioritization of COVID-19 vaccination. <https://www.who.int/publications/i/item/whosage-values-framework-for-the-allocation-and-prioritization-of-covid-19-vaccination>. Accessed 28 Jan 2022.
- [146] WDI (2021), <https://databank.worldbank.org/source/world-development-indicators> . Accessed 28 Jan 2022.
- [147] WTO (2003). "Doha Declaration", [https://www.wto.org/english/res\\_e/booksp\\_e/ddec\\_e.pdf](https://www.wto.org/english/res_e/booksp_e/ddec_e.pdf)
- [148] WTO (2020), "Waiver from Certain Provisions of the TRIPS Agreement for the Prevention, Containment and Treatment of COVID-19, Communication from India and South Africa, WTO Doc. IP/C/W/669", 2 October 2020. IP/C/W/669 <https://docs.wto.org/dol2fe/Pages/SS/directdoc.aspx?filename=q:/IP/C/W669.pdf&Open=True>. Accessed 28 Jan 2022.
- [149] Wu J.T., Leung K., Leung G.M. (2020). "Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study" *The Lancet* 2020; 395(10225):689–97.