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National and Global Vaccine Procurement in a Pandemic Situation: Rational Patent Replacement Option

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Summary:

A standard epidemic challenge requires the development of appropriate new vaccines - with patent-protected active ingredients if necessary - whereby price and innovation competition on the market and contractual agreements between health insurance providers and those in the medical professions essentially determine the costs of vaccinations, for example in the context of a national vaccination campaign. Contributions to the economic literature on vaccine procurement issues have been available since about 2000, including market design approaches – findings that appear to have been ignored by the EU in 2020. Beyond the EU procurement issues, the following is true: with the coronavirus pandemic, a fundamentally new situation is at hand, as it would be insufficient to achieve herd immunity through vaccination only in the North of the global economy. People in developing countries would also have to receive a Corona vaccination as matter of urgency, whereby herd immunity would have to be achieved in all of the nearly 200 countries of the world: Otherwise, the danger of virus mutation is great, and Sars-Cov3 could develop as a new pandemic. In the corona pandemic, there is a special challenge concerning vaccine procurement and vaccine production that should be addressed sensibly by appropriate economic incentives for vaccine development and production. Market design approaches can be complemented analytically by economic-medical pandemic aspects, including open innovation perspectives. While there is a good case to be made for moving somewhat faster vaccine-wise in the North of the global economy than in the developing world, coordinated action within the G20 framework is necessary for a successful pandemic response. To the extent that several countries want licensed production of new vaccines for companies in their country, the option of patent disclosure should be considered, and appropriate compensation for the patent value of the companies concerned should be agreed multilaterally in the event of such disclosure. If a new pandemic results from rapid critical virus mutations, the global economic recovery will collapse in the medium term.

Zusammenfassung:

Eine Epidemie-Herausforderung verlangt nach der Entwicklung entsprechender neuer Impfstoffe – mit ggf. patentgeschützten Wirkstoffen -, wobei der Preis- und Innovations-Wettbewerb auf dem Markt und Vertragsabschlüsse zwischen Krankenkassen und Ärzteschaft wesentlich die Kosten für Impfungen etwa im Rahmen einer nationalen Impfaktion bestimmen. Zu Impfstoffbeschaffungsfragen liegen etwa seit dem Jahr 2000 Beiträge der ökonomischen Fachliteratur vor, inklusive Markt-Design-Ansätze, die von der EU offenbar in 2020 nicht beachtet wurden. Jenseits der EU-Beschaffungsfragen gilt: Mit der Corona-Pandemie liegt eine grundlegend neue Situation vor, da es nicht ausreichend wäre, nur im Norden der Weltwirtschaft eine Herdenimmunität durch Impfungen zu erreichen. Auch die Menschen in den Entwicklungsländern müssten zügig eine Corona-Impfung erhalten, wobei man eben in allen knapp 200 Ländern der Welt Herdenimmunität erreichen müsste: Sonst ist die Virus-Mutationsgefahr groß, Sars-Cov3 als neue Pandemie könnte sich entwickeln. In der Corona-Pandemie-Situation gibt es eine spezielle Impfstoffbeschaffungs- und Impfstoffproduktionsproblematik, die man durch geeignete ökonomische Anreize für Impfstoff-Entwicklung und -Produktion sinnvoll angehen sollte. Markt-Design-Ansätze sind um ökonomisch-medizinische Pandemie-Aspekte, inklusive Open-Innovation-Perspektive, analytisch ergänzbar. Es gibt zwar gute Argumente dafür, dass man im Norden der Weltwirtschaft impfmäßig etwas schneller vorangeht als in den Entwicklungsländern, aber ein koordiniertes Vorgehen im G20-Rahmen ist nötig für erfolgreiche Pandemiebekämpfung. Soweit mehrere Staaten für Unternehmen im Land lizensierte Produktion neuer Impfstoffe wünschen, ist die Option einer Patent-Offenlegung zu erwägen und eine angemessene Entschädigungszahlung für den Patentwert der betreffenden Unternehmen zu vereinbaren. Ergibt sich durch rasche kritische Virus-Mutationen eine neue Pandemie, so wird der globale Aufschwung mittelfristig zusammenbrechen.

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1. Introduction

Following the global coronavirus outbreak in early 2020, numerous pharmaceutical companies launched a vaccine research effort aimed at developing an effective, and safe, new vaccine. Some companies in Europe, the US, Russia, China, India and Iran have apparently succeeded in doing so by early 2021. However, the challenge to produce a sufficiently large quantity of vaccine for the world's 7.9 billion people in as short a time as possible remains in order to achieve herd immunity in the north and south of the global economy, thereby bringing the pandemic to an end. During this transition period, conventional disease control measures are needed, ranging from testing & quarantine approaches to very costly lockdowns. Conventional measures can indeed work very well, as has been shown by some countries, most notably Taiwan, which recorded just seven coronavirus deaths out of a population of 24 million in 2020; New Zealand, Australia, Korea, Thailand, Vietnam, and China have also recorded very low COVID-19 deaths in 2020, while some Western industrialized countries, as well as Brazil, experienced enormously high death rates.

In this field of new vaccines, due to the current medical crisis, vaccine regulatory authorities in the US, the EU, the UK, and other countries, have opted for a rolling accelerated testing procedure, so that, on the basis of already pre-produced candidate vaccines, it was possible to then realize a rapid approval of the various effective and safe vaccines after completion of testing phase III. The extent of the pre-production of vaccines obviously depends to a large extent on agreed advance orders, especially from industrialized countries and emerging economies, as well as from the vaccine consortium led by the WHO, namely GAVI (here specifically: The COVAX Group); GAVI helps poorer developing countries in particular to access these new vaccines by providing a financing grant. One particular problem in the context of the pandemic is that these newly produced vaccines are usually patent-protected - in some cases, this also applies to certain production steps in vaccine production. Given the urgent need to make vaccines available to the world's population soon, this leads to the question of how to efficiently increase vaccine quantities worldwide on the production side through sensible production alliances, government purchase of patents or other methods.

National and international (i.e., multilateral) vaccine procurement programs, such as those launched by OECD countries in the summer and fall of 2020, have a very important role to play in overcoming the disease through vaccine progress. The US, Canada, the UK, the EU and Israel played an important role in this regard. However, the seriousness of the world situation with regard to the risk of epidemics, namely the situation of a worldwide epidemic, has clearly not been thoroughly considered in some countries. This is particularly true for those countries that have not initiated a rapid and quantitatively sufficient (fixed) vaccination order with a clear delivery date - and delivery obligations.

The less sufficient vaccine stocks are available and the later vaccination campaigns start in the north and south of the global economy, the greater the risk of the emergence of new coronavirus mutations requiring adjustments to existing vaccines or even the development of completely new vaccines. If a rapid global vaccination campaign does not succeed, there is the significant risk that an entirely new pandemic situation will emerge in the medium term because of such mutations, and that the economic upswing - that is tentatively emerging in 2021/22 - will end prematurely and a new world recession will result. This perspective, in turn, makes answers to the question of how to rapidly ramp up worldwide production particularly important.

Global vaccine demand in 2018 was 3.5 billion vaccine doses covering all vaccination programs worldwide (WHO, 2019); this results in a global production potential of probably about 5 billion vaccine doses. Thus, a vaccine dose volume of about 16 billion doses – the approximate number of doses needed to fight the coronavirus pandemic (assuming each vaccine is provided in a two-dose regime) - is an enormous challenge for global production capacities. Producing this volume of a new vaccine within one or two years, using conventional pharmaceutical production approaches, under normal production conditions and with the usual time requirements for necessary adjustments, is likely to be considered impossible. It will take a very special effort worldwide to successfully address the global vaccine volume problem needed to control the corona pandemic in a timely manner from the production side. A recent study focusing on global influenza vaccine production capacity (SPARROW ET AL., 2021) provided estimates in this area that the global production volume achieved in 2019 was 1.4 billion vaccine doses, while the annual maximum global production potential was estimated to be about 8 billion vaccine doses. Making a vaccine volume of 16 billion doses available worldwide for a global coronavirus vaccination campaign within two years would therefore appear to be an enormous challenge in terms of scale. This is not to say, however, that this task is not achievable if sufficient production incentives were to be provided by the G20 and other countries, and if special new approaches were to be implemented in terms of an innovative international licensing regime, which amounts to a rapid technology transfer.

Moreover, in view of the coronavirus vaccine campaigns, the worldwide specialized vaccine producers from different technology fields – for example, vector vaccines versus mRNA vaccine producers – are not simply substitutable for each other or readily convertible in the production area in the short term; employees in vaccine production must also have special expertise, which can presumably be taught to qualified workers in just a few months. In any event, adaptation processes would take several months.

Not even the retooling all the existing global vaccine production capacity would apparently be sufficient to produce the 16 billion doses of vaccine needed. It will be necessary to address the global vaccine challenge from the supply side of the pharmaceutical sector in novel ways such as by combining retooled existing vaccine companies with newly built vaccine plants - while employing novel technologies and expanding vaccine production to new countries. Open innovation approaches could also become useful for early phases of the production chain, which will be discussed further on.

The basics of vaccine procurement, including global vaccine production and vaccination aspects, is addressed below. In terms of vaccine procurement, it should be noted that the government purchase of a vaccine is always associated with liability issues: Side effects can arise during any vaccination, whereby such reactions on the part of recipients are especially prevalent with novel vaccines. In principle, such risks are an essential aspect in the further development of new vaccines, but it should be possible to reasonably limit these risks through a professional examination by the regulatory authorities.

The EU launched a common coronavirus vaccine procurement program for EU countries in the fall of 2020, months after the UK and US, meaning relatively small quantities of vaccine were available for EU countries in the first half of 2021. Fundamental issues concerning vaccinations have been addressed early in the literature in 2020 (including WELFENS, 2020). The UK ordered doses of the vaccine from Biontech/Pfizer on July 20, 2020, and again in September, and in addition, the AstraZeneca vaccine was ordered as early as summer 2020. The EU, on the other hand, confirmed the order of 300 million doses of the Biontech/Pfizer vaccine only on November 11, 2020, and 80 million doses from Moderna (EUROPEAN COMMISSION, 2021). The Trump administration placed large orders of both the Moderna and Biontech/Pfizer vaccines early in the summer of 2020; the US Centers for Disease Control and Prevention published considerations on vaccine procurement, vaccine logistics, and US supply and demand development perspectives for corona vaccines in the fall of 2020 (CDC, 2020).

Box 1: EU Order Quantities

The fixed EU order quantities in 2020, namely 300 million doses from Biontech/Pfizer and 80 million doses from Moderna are apparently initially sufficient for 190 million inhabitants across the EU, which - however - has 450 million inhabitants, if two vaccination doses are necessary per person. With this EU ordering policy, it was clear that circa 290 million people in the EU were left without early vaccination protection. A reasonable EU vaccine procurement policy should have been over 2 billion doses of vaccine by September 2020 at the latest - by which time the UK is already placing its second firm order with Biontech/Pfizer. UK orders at year-end 2020 were 350 million vaccine doses for a population of 65 million. High EU optional order numbers cannot hide the fact that, based on H1 2020, no adequate vaccine protection was available at all across the breadth of the EU of about 450 million people. In the fall of 2020, it was still unclear which vaccines would be approved.

EU spending on vaccine procurement was oddly low at just €4 billion in 2020 compared to US spending of $18 billion (about €17 billion); based on U.S. spending, and considering 450 million EU residents - versus 330 million US residents - one should have expected EU spending in the region of €23 billion. It is reasonable to assume that the US traditionally pays higher prices for vaccines than the EU or UK, which should actually benefit the US given the production priorities of vaccine producers; accordingly, about €20 billion would also have been reasonable for the EU as a procurement budget for vaccines. In the case of the EU, the lack of a real political union was a partial problem in terms of the speed of vaccine procurement; the European Commission also had only a partial budget for vaccine purchases and apparently needed political approval as well as complementary budgetary resources from individual EU member countries.

This massive under-procurement on the part of the EU results in enormous costs EU-wide and indeed globally: Medically through needless virus mutation dynamics, meaning thousands of additional COVID-19 deaths and millions of unnecessary COVID-19 infections, and economically through a slowdown of the European and global economic recovery due to a slow vaccination roll-out in the EU. It remains to be seen if the European Parliament fulfils its oversight role by holding the European Commission accountable.

On the question of when and how much vaccine would be available, crucial considerations for achieving rapid herd immunity, the EU apparently did not seek to conclude incentivecompatible contracts with suppliers which would have ensured a rapid ramp-up of production, as procurement contracts published by the EU show. The fact that the EU ordered more doses of vaccine than the population of the EU is in itself irrelevant (especially since some of the suppliers were not completely sure whether their vaccine would really work). This is because later deliveries leading to herd immunity only in winter 2021 are to be classed quite differently to deliveries at an early date with the achievement of herd immunity in the EU in spring 2021. The latter would have significantly limited the mutation possibilities of the virus in the corona pandemic, which is dangerous for the world's population. Slow vaccination progress in the EU, as is foreseeable, will indirectly massively increase the hazard of virus mutations in Europe and worldwide. The so-called South African virus mutation is apparently not adequately protected against by the AstraZeneca vaccine, so on February 8, 2021, the government of South Africa decided to review the vaccination process with AstraZeneca. If the AstraZeneca-Oxford vaccine has to be adapted to meet the challenge of these new mutations, it will likely mean a global slowdown in the fighting of the the pandemic. It is likely that even greater reliance will have to be placed on novel mRNA vaccines than is the case in many countries at present; even if the cooling requirements here are more complex than for the AstraZeneca-Oxford vaccine.

Incidentally, the EU procurement strategy can be described as clearly flawed against the background of the market design approaches available in Economics since about the year 2000: Far too few vaccine quantities were ordered relatively late, apparently on the basis of considerations aimed primarily at shifting liability to vaccine producers and achieving low procurement prices ("fair prices"). The latter in itself is a contradiction in terms:

- If, as in the turbo development of coronavirus vaccines, there is some uncertainty about the safety of the vaccine, especially because of the short development time or the novelty of such vaccines - for example in the mRNA format - then because of the global pandemic situation, which means pressure for rapid vaccination drives, a long research program cannot be set up first in order to investigate all possible long-term side effects of the vaccination in detail and to ensure an absolutely error-free manufacturing process. There is an overriding medical-economic-socio-political interest in a rapid vaccination program so that herd immunity can be achieved expeditiously. If faulty batches of a vaccine are produced, government purchasers could well assume part of the risk of faulty production or the resultant costs in the first year, since not only are the vaccines themselves new, but the production processes are also in part novel and innovative. A flawless vaccine production process is absolutely necessary in principle, but providing clear incentives for production is in the interest of state and society. For incentive reasons, the production risk should be predominantly with the producers, but at least in the early stages of production, some risk sharing between government and companies is worth considering.

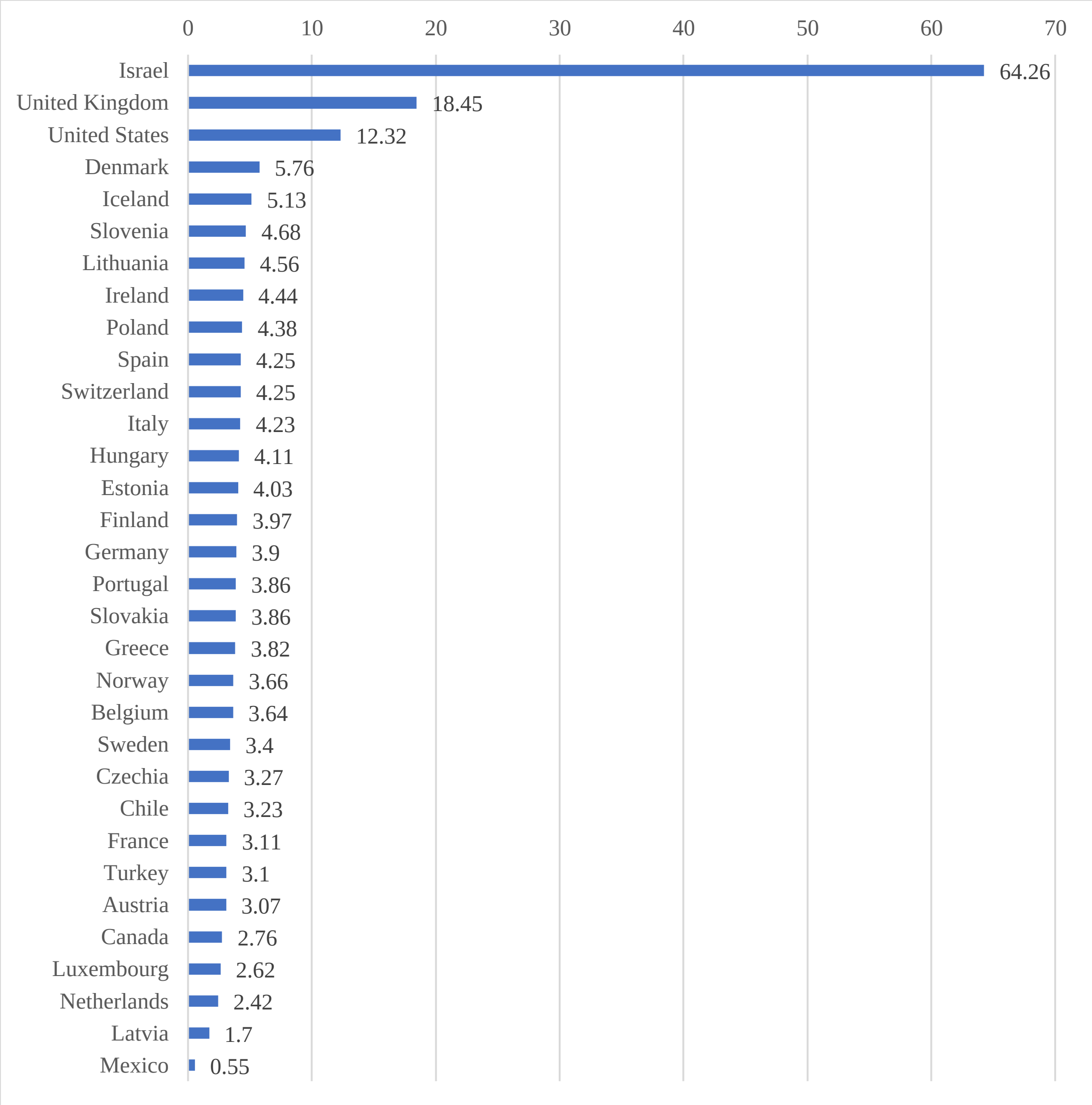
- In the process of negotiations with the vaccine-producing companies, the procuring government agency must either decide that the liability risks are in fact largely assigned to the government, and in return relatively inexpensive vaccines can be obtained, or the liability risks are to be assigned predominantly to the respective vaccine manufacturer, in which case the latter must then be granted a kind of risk premium, since the manufacturing companies must insure themselves against liability risks or implicitly bear the liability risks themselves. It is not reasonable in the case of the AstraZeneca-Oxford vaccine, for example, that only the production costs are reimbursed on the part of the EU, since in this way, the liability risks automatically lie with the EU, as the publication of the EU purchase contract with AstraZeneca shows. This creates a difference in the treatment of liability risks for different vaccines, making it unnecessarily difficult to compare vaccine offers on the market in terms of price – which, in turn, distorts competition on the vaccine market. The EU procurement formula of “no liability risks for the government as far as possible & very low prices” is a contradiction in terms. The innovation situation in the development of the novel mRNA vaccines (and other novel vaccines) suggests in any case that an appropriate innovation premium would have to be provided. Incidentally, it should be pointed out that in Germany, for example, the state has assumed enormous liability risks in nuclear power production for decades without complaint - a nuclear power plant only has to have €2.5 billion in insurance liability, which is about $1/2500^{th}$ of the estimated costs for a serious nuclear power plant accident. In contrast, the EU’s vaccine procurement policy in 2020, apparently also covered by parts of the German government, seems strange, by making the liability of vaccine suppliers a major point in negotiations with the companies.

With the real launch of vaccination campaigns across the global economy on December 14, 2020, in the United Kingdom and shortly thereafter in the United States, Canada, Israel, the EU and other countries, it has become clear after just over two months that:

- Israel is ahead by far in terms of the international vaccination table and will likely have vaccinated its entire population once by the end of February 2021; it will also have administered numerous second vaccinations by that month. The United Arab Emirates is also far ahead in the international field of immunization coverage. The UK and US are in a middle leading position and are expected to be close to 20 percent and 13 percent of the population, respectively, vaccinated at the end of February, while EU countries will have barely vaccinated 5 percent of their populations.

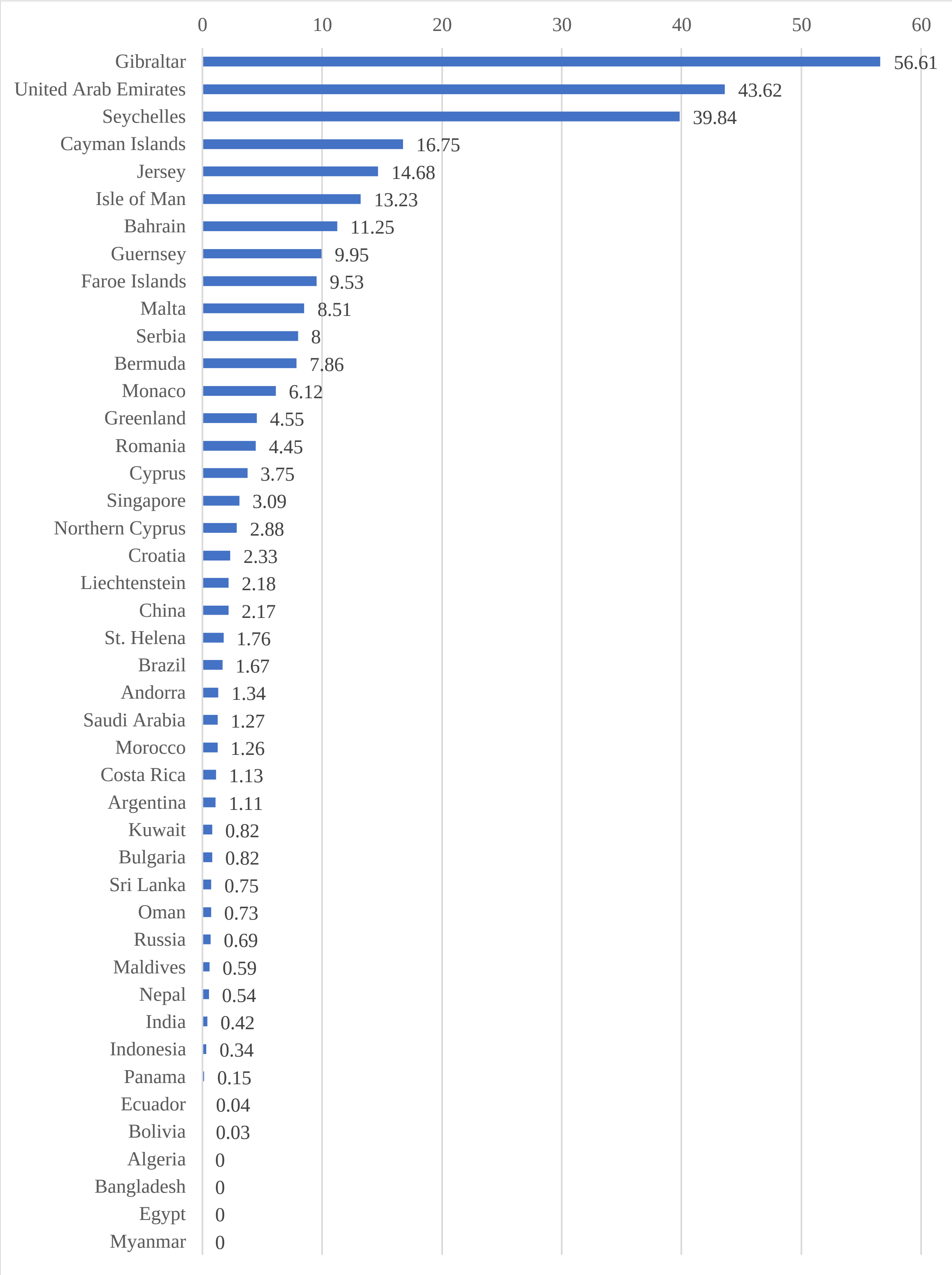
- The start of vaccination roll-outs in developing and emerging countries has been decidedly slow, with China - and, with significant cutbacks, India - nevertheless quite well positioned. There is no foreseeable rapid vaccination in the global South, so that the virus will probably find very favorable mutation conditions there throughout 2021 and 2022 (beyond the South African variant which was discovered in January 2020).

Fig. 1: Vaccination rates in OECD countries at the beginning of February 2021



Source: Own representation of data available from Our World in Data; as of 08.02.2021.

Fig. 2: Vaccination rates in emerging and developed countries at the beginning of February 2021



Source: Own representation of data available from Our World in Data. As of 08.02.21.

2. The pandemic challenge and approaches to solutions

The coronavirus pandemic situation represents additional special challenges which need to be considered. Assuming that vaccinated people cannot infect others - or are much less likely to do so than non-vaccinated people - vaccination is in part a public good: A vaccinated person is protected; moreover, the likelihood of infecting others is reduced. In view of the usual international travel and international transport and economic interdependencies, vaccination indeed partly represents an international public good. It makes sense therefore to subsidize vaccinations or even provide them free of charge, provided that there are corresponding positive external effects of vaccination (i.e., that the social benefit is greater than the individual protective benefit). In the case of positive international external effects, a multilateral or, in the borderline case, a global innovation premium for innovative vaccine-producing companies from OECD countries, Russia, India and China is desirable, whereby emerging countries should also contribute to the financing of such an innovation premium. After all, it is precisely those people in emerging countries who are anchored in the global economy through trade, direct investment, migration and tourism who benefit from a global vaccination campaign.

In a simplified schematic representation, the overcoming of the global pandemic as an economic-medical challenge is as follows:

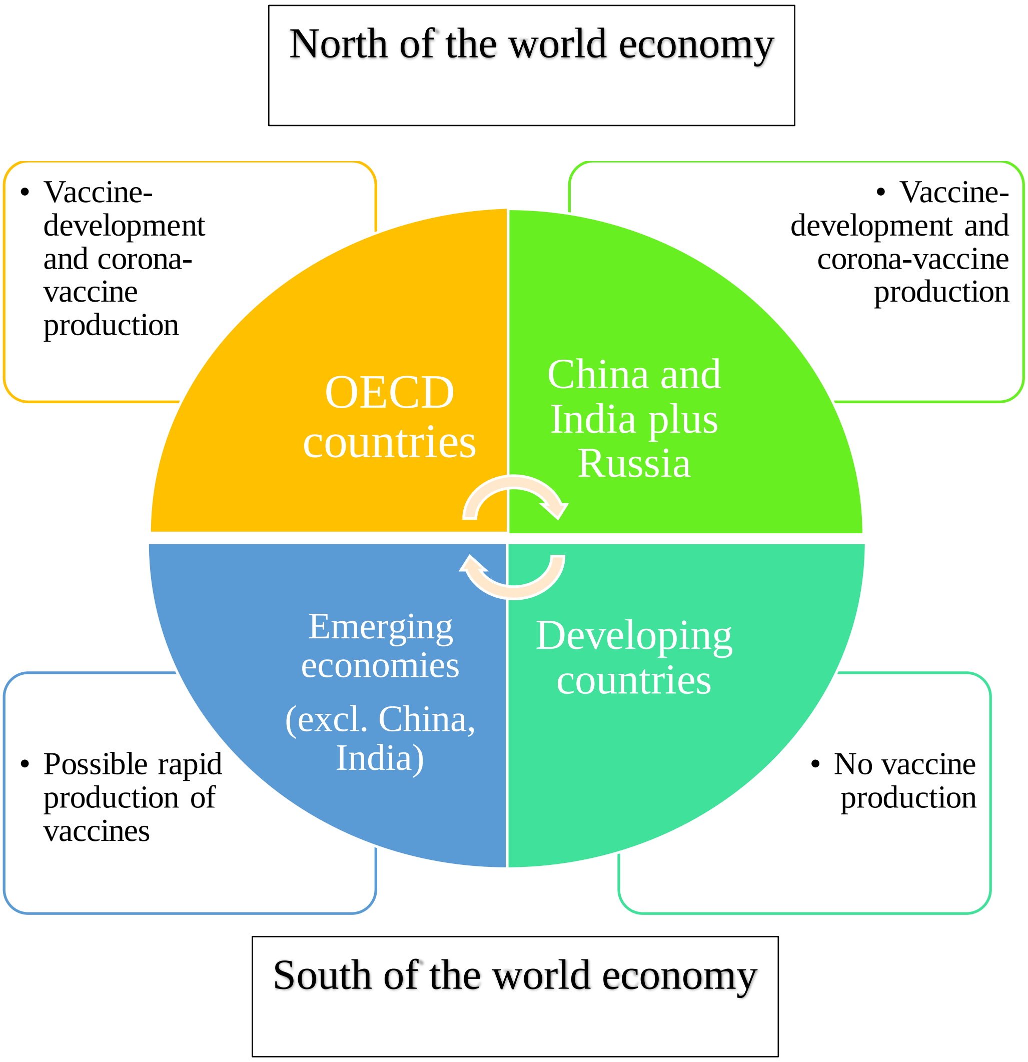
- Corona vaccines have been developed in 2020 in the North of the world economy - the North here includes China and India and, of course, Russia as an established industrialized country - and are also produced there. Vaccinations for almost all people across the global North are necessary.

- In the global South - consisting of emerging economies (defined here as excluding India and China) and developing economies - vaccines are also needed for almost everyone; vaccine production could arguably occur in principle in some emerging economies.

- If the global North brings about an unnecessarily slow vaccine production - such as through the European Commission’s questionable procurement policy - then this not only leads to an unnecessarily tardy and mutation-risky vaccination campaign in the North, but the economic recovery in the North of the world economy is also slowed down. This, in turn, damages the chances in the global South to quickly overcome the corona recession.

- When it comes to accelerated and efficient global vaccine production, efforts should be made to include producers from emerging countries in coronavirus vaccine production; there were no proposals on this from policymakers until early 2021. In the context of the G20, ways to systematically include emerging countries as suppliers or producers of vaccines could have been discussed as early as the turn of the year. The exact potential of possible vaccine production in emerging countries (excluding India and China) can at least be gauged on the basis of a list from the World Health Organization (WHO) and on the basis of export figures in the pharmaceuticals sector - possibly supplemented by the chemicals sector.

Fig. 3: Pandemic North-South aspects: Vaccine production prospects



Source: Own representation

Solution elements for pandemic control

It is plausible to look at a list of countries in the world economy where there is potential for vaccine production. Such countries could also be found in the global South; and to the extent that this is not the case, it would at least be worth considering the scope of the technology gap and exploring ways to close this gap via new approaches in terms of cooperative North-South research and other forms of technology transfer.

The following list of the World Health Organization suggests that Indonesia could be a major additional coronavirus vaccine producer - especially if there were an expeditious licensing of vaccines and vaccine production patents. It is also possible that Serbia and Mexico could emerge as additional vaccine producers, which, unlike Indonesia, have not yet been identified in the WHO list as prequalified for vaccine production in 2020 (see Table 1). With an organized international technology transfer to additional countries, the number of countries with corona vaccine production facilities could probably be expanded even more and, in addition, the question also arises whether the number of producers of supplier materials for vaccine production could not also be rapidly increased; in both areas, the WHO and the World Trade Organization (WTO) as well as the G20 as an institution or group of countries are obviously challenged.

Tab. 1: List of vaccine-producing countries with functioning National Regulatory Authority (NRA); standard is WHO-pre-recognized vaccine producer status

List of vaccine producing countries with functional NRAs

The National Regulatory Authorities (NRAs) in the listed vaccine producing countries were assessed against the WHO vaccine assessment tool and announced as "functional NRAs" before introduction of the Global Benchmarking Tool (GBT) in 2016.

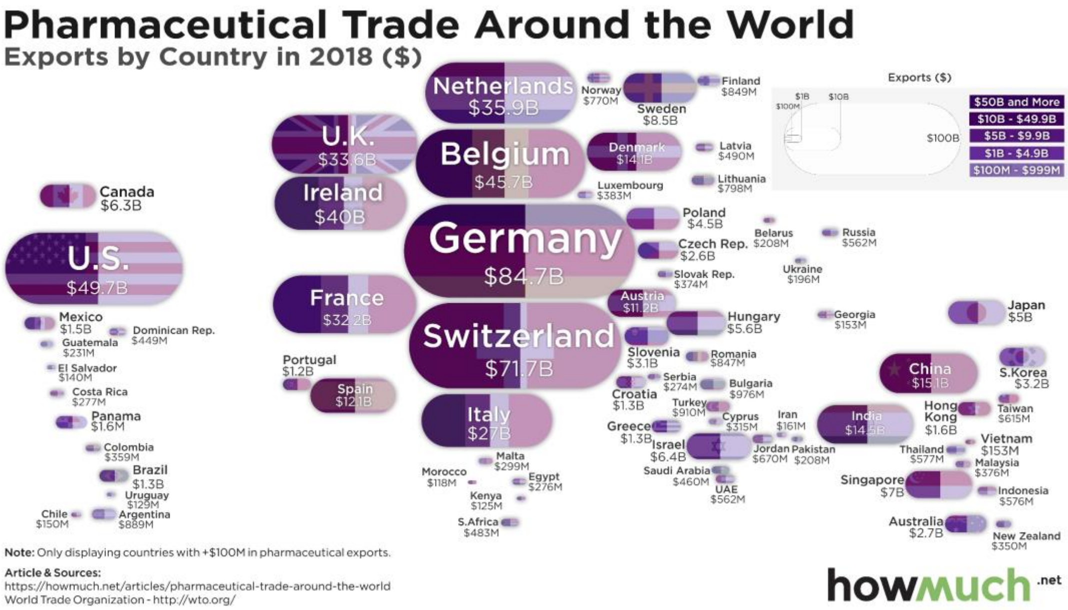
The list will be updated regularly as new information becomes available.

Country	Is the country producing one or more WHO prequalified vaccine?
1. Australia	producing WHO prequalified vaccine(s)
2. Belgium	producing WHO prequalified vaccine(s)
3. Brazil	producing WHO prequalified vaccine(s)
4. Bulgaria	producing WHO prequalified vaccine(s)
5. Canada	producing WHO prequalified vaccine(s)
6. China (People's Republic of)	producing WHO prequalified vaccine(s)
7. Cuba	producing WHO prequalified vaccine(s)
8. Denmark	producing WHO prequalified vaccine(s)
9. France	producing WHO prequalified vaccine(s)
10. Germany	producing WHO prequalified vaccine(s)
11. India	producing WHO prequalified vaccine(s)
12. Indonesia	producing WHO prequalified vaccine(s)
13. Islamic Republic of Iran	not producing WHO prequalified vaccine
14. Italy	producing WHO prequalified vaccine(s)
15. Japan	producing WHO prequalified vaccine(s)
16. Mexico	not producing WHO prequalified vaccine
17. Netherlands	producing WHO prequalified vaccine(s)
18. Republic of Korea	producing WHO prequalified vaccine(s)
19. Russian Federation	producing WHO prequalified vaccine(s)
20. Serbia	not producing WHO prequalified vaccine
21. Sweden	producing WHO prequalified vaccine(s)
22. Switzerland	producing WHO prequalified vaccine(s)
23. United Kingdom of Great Britain and Northern Ireland	producing WHO prequalified vaccine(s)
24. United States of America	producing WHO prequalified vaccine(s)

Source: WHO (2020), last updated 23 June 2020
https://www.who.int/medicines/regulation/functional_nras_vaccine_producing/en/

As can be seen from an illustration of global pharmaceuticals exporting countries, the potential of countries that could supply important inputs for vaccine production is likely to be very large. Figure 4 shows that the list of potential supplier countries here is very long: Around 50 countries could possibly be considered therefore as sites of vaccine production or as suppliers of inputs for vaccines. Relative to gross domestic product, Switzerland and Ireland are leading global pharmaceutical exporters, so it is surprising that companies from these two countries have so far had little direct involvement in corona vaccine production - with the exception of Novartis from Switzerland.

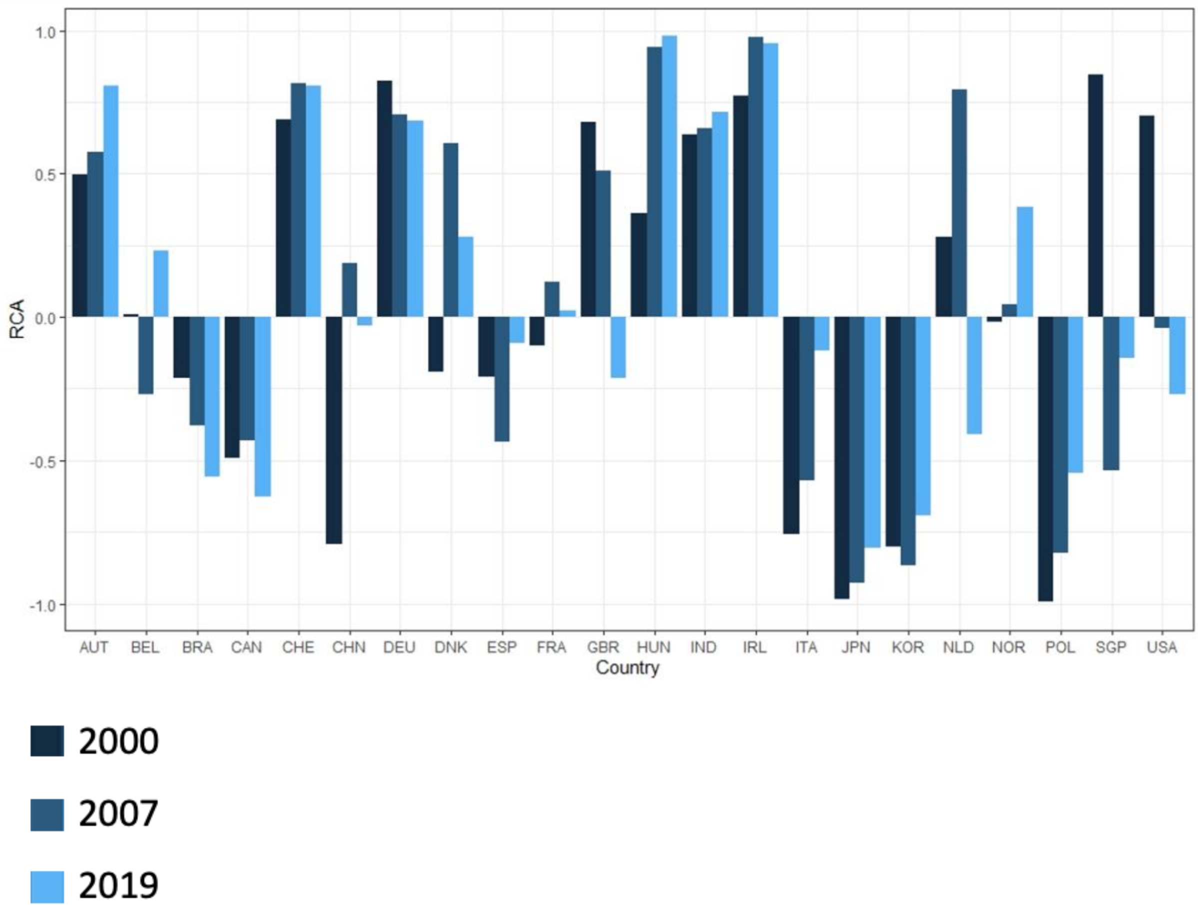
Fig. 4a: Pharmaceutical exporting countries (with export value of more than $100 million in 2018).



Quelle: howmuch.net, https://howmuch.net/articles/pharmaceutical-trade-around-the-world

It goes without saying that little can be derived from absolute export figures in terms of potential productive capacity for pharmaceutical products and vaccines in particular. Of course, there is considerable specialization in the global economy, as a glance at the RCA values in the pharmaceutical sector for selected countries already shows (see Fig. 4b; RCA stands for revealed comparative advantage of the sector *i* under consideration). Brazil, Canada, Japan, the Republic of Korea and Italy, for example, are negatively specialized in the pharmaceutical sector - 0 stands for an indicator value that is neutral or where the export-import ratio corresponds to the average for all goods, with the indicator value normalized to the value range -1 to +1. Austria, Germany, Hungary, India, and Ireland were consistently positively specialized in pharmaceutical products from 2000 to 2019 (more precisely, in 2000, 2007, and 2019). Successful international production specialization is usually preceded in time by a corresponding innovation specialization, and the evaluation of patent statistics is usually used here. In terms of pharmaceutical innovation and vaccine and drug innovation strength, the RCA chart below is likely to be informative; however, when it comes to the question of basic capabilities to participate in global coronavirus vaccine production, the list of pharmaceutical exporting countries is actually likely to be more useful. It is indeed an unusual question to ask in combating the pandemic: What companies could contribute efficiently to vaccine production worldwide? The answer to this, of course, is highly dependent on technological capabilities and the availability of a skilled workforce, but also on whether companies from emerging markets have to pay high royalties for vaccine production, for example. It would make sense to use some of the Western aid for developing countries to subsidize such royalties. It is also conceivable that, in the special situation of the pandemic, the G20 countries (or the OECD countries) could provide incentives for venture capital firms from the global North to become financially involved in the founding of companies in the global South or in supporting companies there to become involved in the production of vaccines. Ultimately, the global North will also benefit from an efficient increase in vaccine production output, namely faster vaccinations at lower cost and lower health insurance costs than would otherwise be the case; for the South of the global economy, similar arguments can apply

Fig. 4b: International revealed competitive advantages (RCA) in the pharmaceutical sector; selected countries, 2000-2019



Source: Own calculations based on data available from COMTRADE

Looking at patent application numbers in an international comparison, beyond the OECD countries, Cuba may also be among the countries that can meaningfully contribute to overcoming the pandemic in the area of vaccine development and production. In the global emergency situation of a pandemic, it is to be hoped that political tensions, for example between the US and Cuba, would not prevent or significantly slow down meaningful Cuban involvement in vaccine production.

Tab. 2: Number of pharmaceutical patents by priority country, as of 10/02/21* (ranked from highest to lowest)

Priority Country	Patents	Priority Country	Patents	Priority Country	Patents
US	113,761	Chile	103	Samoa	2
Japan	36,567	Latvia	98	United Arab Emirates	1
UK	28,732	Ukraine	96	Antigua and Barbuda	1
Germany	17,103	Iceland	74	Bosnia & Herzegovina	1
France	16,435	Malaysia	69	C.A.R.	1
China	9,861	Lithuania	60	Cyprus	1
Rep. of Korea	8,554	Serbia	50	Algeria	1
Italy	6,633	Slovakia	39	Gabon	1
India	5,434	Kazakhstan	21	Ghana	1
Switzerland	4,227	Philippines	20	Equatorial Guinea	1
Sweden	4,221	Indonesia	19	Kuwait	1
Denmark	2,966	Jordan	18	Liechtenstein	1
Australia	2,358	Thailand	18	Montenegro	1
Hungary	2,017	Egypt	16	Seychelles	1
Spain	1,681	Colombia	15	Sudan	1
Canada	1,209	D.P.R. Korea	15	Senegal	1
Israel	1,186	Estonia	14	Eswatini	1
Netherlands	1,092	Panama	13	Tajikistan	1
Russian Fed.	865	Iran	11	Zimbabwe	1
Turkey	678	Peru	9	Tajikistan	1
Austria	637	N. Macedonia	8	Zimbabwe	1
Brazil	554	Dominican Rep	7		
Finland	465	Kenya	7		
Greece	429	Morocco	7		
South Africa	398	Monaco	7		
Belgium	354	Tunisia	7		
Luxembourg	299	Belarus	6		
Mexico	298	Georgia	5		
Poland	282	Moldova	4		
Czechia	272	Nigeria	4		
Bulgaria	268	Saudi Arabia	4		
Cuba	239	Sierra Leone	4		
Portugal	239	Syria	4		
Slovenia	229	Costa Rica	3		
New Zealand	219	Viet Nam	3		
Singapore	204	Albania	2		
Ireland	193	Armenia	2		
Norway	157	Bahrain	2		
Croatia	127	Ecuador	2		
Romania	118	Sri Lanka	2		

Source: World Intellectual Property Patentscope Database as of 10/02/2021 https://patentscope.wipo.int/search/en/search.jsf

Note: Figures returned based on a patent search by Front Page term "pharmaceutical", country data is based on returns for each country as Priority Country and only single family member patents are presented.

Vaccination perspectives

The initial goal of a national vaccination campaign is to achieve national herd immunity, which requires a certain minimum vaccination rate, about 70-80 percent in the case of a coronavirus epidemic. However, this is a global epidemic, and the particular circumstances of a pandemic mean special challenges to consider vis-á-vis a national immunization strategy in OECD countries. Overall, if one does not consider that despite very high priority vaccination coverage in the North of the global economy, a prolonged period without herd immunity being reached in developing countries gives the virus time to produce new, aggressive mutations against which the novel 2020/21 vaccines may not be effective, one is overlooking the serious risk of a renewed pandemic in the (near) future undermining the global economy as well as other important aspects of concern:

- The greater the North-South difference in vaccination intensity or herd immunity, the greater the risk of a serious “viral mutation” leading to a new pandemic.

- Due to the pandemic situation, and the fact that only companies in OECD countries, Russia, India and China (and probably Iran) can provide effective and safe new vaccines on a large scale, there is a vaccine pandemic problem on the production side: There would be no lasting herd immunity to Sars-Cov2 (COVID-19) in the northern part of the world economy unless countries in the southern part of the world economy were also rapidly involved in broad vaccination actions and possibly also vaccine production. Apart from South Africa and wealthy Arab oil-producing/Maghreb countries plus Nigeria - as a country with its own vaccine financing capacity - there are about 900 million people in Africa in need of corona vaccines (for some population data for countries in Africa, see Appendix 1) without having sufficient budgetary resources in these countries for extensive vaccine purchases on the world market. Providing for these people in Africa is likely to cost at least about €10 billion; part of the necessary vaccine budget is likely to be provided by foundations and funds from the World Bank, the African Development Bank, and IMF special funds.

- To the extent that the European Commission has negotiated flawed contracts in terms of production incentives, mistakes made in the fall of 2020 cannot simply be compensated for by a price policy readjustment in the spring of 2021: Insufficient pre-production incentives in fall 2020 mean that the very inadequate vaccine production volumes in the EU - and in other countries - can only be substantially increased to a small extent on a tight timeline by improved price offers for additional production of vaccines in the first half of 2021.

- Failure to rapidly achieve an effective global vaccination approach not only threatens new medical pandemic-related problems, but could also lead to a new massive income-dampening global economic crisis - particularly in the context of disrupting international supply chains.

The question arises as to what a globally effective rational vaccination policy should look like in the special context of the current pandemic. People in developing countries would also have to receive a coronavirus vaccination quickly, whereby herd immunity would have to be achieved in all of the almost 200 countries around the world: The dangers of mutations of the virus are all the greater, the longer the pandemic lasts, whereby there is a risk that a completely new type of virus mutation results in a new pandemic (“SARS CoV-3”) which could have a significant negative effect on the world economy in the medium term. This would have enormous medical and economic consequences. While the public health policy discussions at the beginning of 2021 in industrialized countries have been mainly dominated by questions concerning the short-term availability of vaccines, it seems that strategic global aspects of effective and efficient pandemic control are partly overlooked.

It is therefore not reasonable to treat the current pandemic - from the point of view of those interested in vaccination programs in Europe and worldwide - in the same way as one might treat a national or regional influenza epidemic. What is necessary for successful pandemic control is that about 75 percent of people in all countries are vaccinated in the shortest possible time. With 7.9 billion people globally and an assumed need of two vaccination doses per person, about 16 billion vaccine doses are needed; preferably by the end of 2021 or at least during 2022. The vaccine doses available for the first half of 2021 in the EU are far too few in number, and this is similarly true for the global economy as a whole based on known production schedules from early 2021. Interestingly, mRNA vaccines are easier to produce than traditional vector vaccines, while the latter have the advantage of being easier to deploy because the cooling required is less than for mRNA vaccines. For people living in cities in the South of the global economy, mRNA vaccines could become relatively important, as demanding cooling requirements can certainly be achieved in urban centers of developing countries. It should be noted that there are five different types of new corona vaccines available.

Vaccine production varies in complexity for the different coronavirus vaccines and dozens of companies and inputs are needed to produce the new vaccines to a high quality. In the summer of 2020, the EU should have placed a binding order for more vaccines at reasonable prices in good time than it did with a mini-budget of €2.7 billion - a reasonable order of magnitude would have been around €12 billion, as a good 2.5 billion doses should have been ordered and the production side and the relevant costs should have been specifically considered and covered.

High vaccine pre-production levels in the short term can only be realized at relatively high cost, and real pre-production incentives are essentially only created by binding purchase commitments; from the producer’s point of view, the economic value of ordering options is relatively low, especially since a large purchaser will typically have vaccination options granted by several suppliers. The likelihood of options becoming firm orders then appears relatively low from the perspective of individual vaccine-producing companies; this reduces the incentive to expand production capacity.

It is noteworthy that the AstraZeneca-Oxford vaccine was purchased by the British government without a profit margin, so that the British-Swedish company AstraZeneca - which is not actually a recognized leader in vaccine research - apparently produces the vaccine developed at the University of Oxford primarily for reputation gains. On the one hand, this construction sounds philanthropic, but on the other hand it makes it difficult for other vaccine producers to develop and market vaccines based on their own innovations at adequate prices. At the same time, the potency of the AstraZeneca-Oxford vaccine is also significantly lower than that of the two mRNA vaccines from Biontech/Pfizer and Moderna (Biontech is a company from Germany, Pfizer - as production and distribution partner - is a US company; and Moderna from the US). With Johnson & Johnson announcing a successful vaccine, another vaccine supplier appeared in the US at the beginning of February; with the special feature that only one vaccination dose is necessary.

3. Patent protection issues and solution perspectives

With regard to the pandemic, the question arises in particular of how to rapidly realize a global vaccination campaign that effectively and efficiently defeats the pandemic. A rapid ramp-up of vaccine production capacity worldwide is important in this regard. In this context, the question arises of whether the coronavirus vaccine patent protection should in principle be lifted to ensure the rapid global availability of the new vaccines.

In principle, the market economy system is designed in such a way that certain innovations receive temporary copycat protection through a patent, which formally amounts to 20 years legal protection. However, in the course of “counter-innovations”, effective patent protection often amounts to rather 2/3^{rds} of this period and then allows a monopoly price premium on the market during this time, which, as a Schumpeterian price bonus, represents a risk premium for the successful innovator and is intended to secure the financing of the often high costs in the area of research & development (R&D) and, in addition, to reflect the positive external benefit effects - which require a higher production volume than a company will normally plan under purely competitive conditions with a view to its own benefit or profit considerations. The innovation bonus in the monopolistic market price is a positive signal for future innovators to accept the risks of the innovation process; and, moreover, from a theoretical point of view, the price innovation bonus for the innovator should ultimately cover the positive externalities - that is, the additional societal benefits beyond the innovative firm itself. In the case of a coronavirus vaccine, where the vaccinated person cannot infect others, it should be noted here:

- From the perspective of OECD countries, and many other countries, with trade and travel contacts, it is fundamentally a matter of both the national and international positive externalities of the vaccine in question.

- A particularly high positive externality, which must be considered in terms of vaccinations from an economic priority point of view, naturally arises for all employees in the R&D and innovation sector; they should be included in a special priority group and vaccinated with priority. In OECD countries, about 2 percent of the workforce is likely to be part of the innovation sector (in the broader sense), and higher education should be included here. Experienced researchers have increasing labor productivity with age (AIYAR/EBEKE/SHAO, 2016); presumably they also represent large positive externalities in the innovation sector.

From the point of view of modern economic analysis, patent protection is not an optimal instrument for the internalization of positive external effects (KREMER, 1998): In principle, even an innovative monopolist - on the basis of a patent, this market position exists - cannot easily appropriate the consumer surplus of the users of the innovative good. Thus, even in the case of a monopoly, the price position on the market is not easily such that efficient incentives for further innovations arise. In the absence of patent protection, the incentive to innovate is even more likely to be too low, as the economic history of Switzerland and the Netherlands in the 19th century shows: At the time, patent protection was dispensed with in both aforementioned countries and this, in the light of a very liberal zeitgeist, was considered to be a particularly sensible regulation, since the whole of mankind would now be able to use and benefit from the respective innovations. Both countries later reintroduced patent protections, as it became clear that without patent protection, there were no reasonable incentives for further innovation (WELFENS, 1990).

Michael Kremer has developed the proposal (KREMER, 1998) that the government could purchase patents in an auction and then make them available to the public free of charge in a random selection mechanism; or - following the result of the random selection - auction them off to a private supplier in another auction to have a mechanism for the adequacy of government purchase prices. However, Kremer did not address international internalization issues. Moreover, in the case of a pandemic, the above random mechanism cannot reasonably come into play, since one will otherwise possibly replace a private monopolist in the initial situation with a new private monopolist.

If, in the special case of a pandemic with regard to novel vaccines, one considers a kind of general licensing as an option of the state, one would have to consider how to give companies a kind of substitute innovation profit bonus for their special innovative achievements, which would be equivalent to the innovation bonuses to be expected in the normal case resulting from the ownership of patents for the vaccine's active ingredient. If patents were simply taken away from companies and a - at first glance inexpensive - compulsory licensing of production were to be imposed, this would destroy a great deal of confidence in the economy and act as a long-term negative incentive with regard to innovation dynamics, not only in the pharmaceutical industry. For this reason, compulsory patent disclosure without an appropriate financial compensation for innovative pharmaceutical companies is out of the question for fundamental incentive reasons.

In the case of coronavirus vaccines, however, one cannot easily use the simple national Kremer patent purchase mechanism either, since the positive externalities of vaccinations are international and one would indeed now have to involve a large number of countries in a financial compensation solution for the pharmaceutical innovator. At what level of political cooperation one should raise the funds for such a compensation solution would have to be examined. The G20 would probably be the most favorable option, although a rapid consensus cannot be expected here without further ado:

- Per capita incomes (according to purchasing power parity) of the countries involved are relatively unequal, which means large differences in interests;

- some of the countries involved are vaccine-producing countries according to the WHO list, and some of the countries are only in a vaccine-receiving country situation, so there are other conflicting interests.

- Nevertheless, a group of 20 countries comprising the major vaccine-producing countries to date is relatively manageable, which should be an advantage over a complicated UN solution. However, following a G20 consensus, a UN consensus can then also be sought, with the UN having a fundamentally important role to play in terms of pandemic response; of course, this consideration applies in particular to the World Health Organization.

Newer market design approaches aim to develop market-based incentives that are welfare-maximizing in certain market constellations, such as the development of new drugs for rare diseases or in the case of an epidemic. In principle, market design approaches can also be used to formulate an optimal solution with regard to incentives for pharmaceutical innovations, including vaccine development and production.

When (common) vaccines are introduced into the market, innovative pharmaceutical companies offer new vaccines in different countries, where governments and health insurance companies realize the funding of national vaccination campaigns. Occasionally, large foundations also want to participate in the purchase of new vaccines, whereby considerations have been developed in the economic market design approach, amongst others, for this: How would one have to set prices sensibly or negotiate contracts so that sufficiently high numbers of vaccines can be made available in a certain period of time, especially for poorer countries. KREMER/LEVIN/SNYDER (2020) and many Kremer co-authors have published numerous research papers on this complex of questions since about 2000, a literature which should be known by OECD country governments and the European Commission (but a body of work that probably is not known to policymakers, at least in many countries, where the vaccination procurement process was probably also not shaped by experts with sufficient knowledge of markets and economics). The article by KREMER/LEVIN/SNYDER explicitly considers the coronavirus vaccination issues - but without any appreciation of particular pandemic aspects.

KREMER ET AL. (2020) present a formal analysis for Advance Market Commitments (AMCs) aimed at increasing vaccine production in low-income countries - where there is a specified subsidy rate from a grant fund until it is exhausted; the approach is also appropriate for coronavirus vaccine supply in poor countries. The optimal AMC design depends largely on the stage of market development of the vaccine product under consideration. In addition, the level of sunk costs plays an important role, as does, usually, the achievement of certain Nash equilibria in the context of game theory approaches.

The additionally important pandemic perspective brings two analytical components:

- There is a link between herd immunity achievement in the global North (country 1) and South (country 2), with a risk of setbacks for country 1 because of mutation possibilities of the coronavirus in the slower vaccinating country 2. A special feature that can be assumed is that corona vaccines are produced only in the North of the world economy and the countries in the South of the world economy have a lower average age of the population than the countries in the North. This is important because this age difference argues for some temporal preference in terms of the vaccination process for the North. The level of urbanization in the South of the world economy is also somewhat lower than in the North, on average, which in turn suggests lower coronavirus pandemic contagion risks for rural regions in the South of the world economy – and is more so than is true for rural regions in the global North.

- There are economic interdependence effects to consider: If vaccinations are carried out somewhat faster in the North than in the South, this minimizes the global death toll:

This is because the economically asymmetrically large expansion effect when the epidemic is brought under control in the North brings relatively strong economic export or expansion effects for the South of the global economy through trade mechanisms, raising the incomes of more people above subsistence levels. Of course, it is also urgent that people in developing countries have sufficiently high numbers of vaccine doses available in a timely manner. However, developing countries are helped by competition between the major powers of the US, China, Russia, and the UK (as well as India and the EU), with the respective powers wanting to engage in "vaccine giveaways" to countries in the global South for geopolitical reasons. Complementary players in supplying or funding vaccine doses to the South are foundations from OECD/G20 countries and also from some emerging economies.

Politically, this could be understood to mean that some temporal vaccination bias on the part of the North might be justified. Incidentally, the political economy of the pandemic in any event works in OECD countries in such a way that in vaccine-producing countries, the vaccination rate will be relatively high, because in Western democracies, politics comes under strong pressure to vaccinate the respective domestic population with priority. In this view, Germany - one might critically note - is in a peculiarly poor position, having given away this natural policy preference by ceding vaccine procurement decisions to the EU. This is likely to lead to political tensions in Western Europe.

4. Vaccine procurement issues and special pandemic aspects.

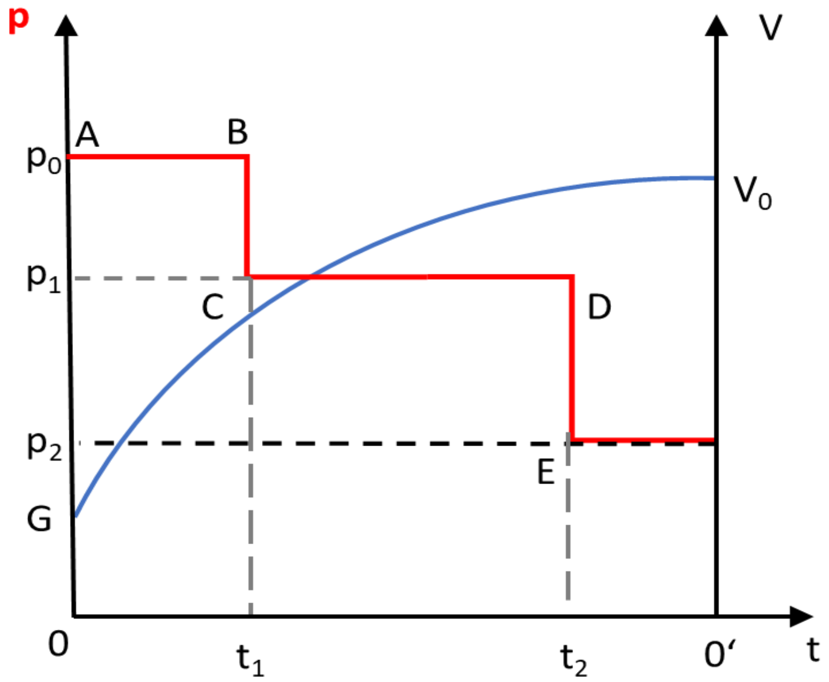
In the event of an epidemic, the purpose of a national vaccination campaign is to immunize a sufficiently large proportion of the citizenry through a safe and effective vaccination: The goal is to achieve herd immunity so that new large epidemic outbreaks can be reliably prevented and thus normal economic development - with a normal, usual social life - becomes possible once again. Local epidemic outbreaks could continue to be controlled by contact tracing, quarantine measures and the use of medication by the infected persons concerned within the framework of normal health policy.

At the start of a vaccination program, there will inevitably be a particular shortage problem, since vaccine production cannot be ramped up arbitrarily quickly. However, the production of new promising vaccine candidates can be ramped up in advance by the company before vaccines are even approved by the authorities. If one wants to have larger quantities of vaccine already available in the first phase of the vaccination program in a country, this is only possible if one has vaccines pre-produced by promising "vaccine candidate companies" against the reimbursement of costs before the final Phase III of vaccine testing is completed and can offer relatively high prices for the first deliveries of vaccines - in the first quarters, when herd immunity has not yet been achieved; this is consistent with the logic of Advance Market Commitment according to market design approaches. Accordingly, prices would have to show some sort of staggering over time. Nothing of this sort is visible in the procurement strategy of the European Commission and nothing can be seen in the partially published document specifically on the purchase of the AstraZeneca-Oxford vaccine. The unit price agreed by the EU can be considered as strange and, in any event, inefficient, if one had wanted to secure the early high production levels with a reliable supply.

Procurement price development for vaccine procurement

Elementary principles of the market design approach for vaccine markets immediately suggest that in an initial procurement phase - when the vaccination rate is still low - the procurement price is agreed at a relatively high level in order to secure a minimum initial quantity of vaccines. After an initial phase in the period t=0 to t_1, the price lies at p_0 (see distance AB with the vaccine price level). In a second phase - t_1 to t_2 - the procurement price is lowered to p_1, since now with the already procured quantities one is approaching the critical inoculation ratio V_0 which corresponds to herd immunity. In the third phase, i.e. from t_2 to t=0', a further reduced procurement price p_2 applies. The vaccination rate development over time is characterized by the curve GV_0.

Fig. 5: Vaccination rate development (V; V_0 is the vaccination rate required for herd immunity) and procurement price development (p) on the vaccine market.



Source: Own representation

In an international competitive process, innovative pharmaceutical companies will develop vaccines in the case of a normal epidemic while being able to enforce at least monopolistic price surcharges on the markets for vaccines over many years on the basis of patents obtained for the active ingredients used in each case. These price premiums must be high enough to cover the innovation-related expenditures for R&D as well as the risk costs of the innovation. Without such price premiums, innovative pharmaceutical companies will disappear from the market in the longer term, and the global innovation dynamic will then decline massively. This would massively limit the prospects, both nationally and globally, of coping with any new epidemic that might arise in the near future, so patent protection is fundamentally important.

Pandemic Aspects

Nevertheless, in the pandemic situation, one must consider whether patent purchases should not be undertaken for sensible reasons, in which the state - or a community of states acting in unison - provides a kind of time-lapse innovation remuneration so that companies, foregoing patenting, enable worldwide and thus the maximum possible level of production; licensing by the state does not necessarily have to be free of charge, but it must be ensured that herd immunity is achieved in all countries at the level of the global economy. This amounts to the state purchase of patent protection. The amount to be paid should not be confused with government production premiums for the pre-production of vaccines before market approval (as granted by the EU to some companies). The EU has also granted some research funding to some companies in the EU in 2020. On the other hand, it would be economically efficient if the coronavirus vaccine research expenditures of Oxford University were jointly funded by the G20 countries; this applies similarly to the Biontech/Pfizer vaccine and to the other successful vaccines of other manufacturers.

The amount of compensation to be granted to a company that foregoes patent protection is difficult to determine, as one would have to simulate the market development phase of a good ten years and have the patent compensation calculated by a panel of experts on the basis of expected prices and market shares. The patent compensation amount would have to be raised jointly by the countries using the vaccine, which would require an international negotiated solution at least at the G20 level. In this context, there are different interests on the part of countries that are the location of innovative vaccine manufacturers versus countries which are not home to such vaccine producers. Countries that have innovative vaccine manufacturers could be at a macroeconomic disadvantage on the capital market side and in terms of the exchange rate - with an appreciation effect due to capital inflows as a result of investors wanting to invest in promising companies - if there is a temporary global softening of patent protection; at least if government patent purchases are classified as a signal for a long-term softening of patent protection - particularly since growth dynamics in the North of the global economy (with many innovative companies) could be impaired. Ultimately, this could also be detrimental to the countries in the South of the global economy, whose export growth will be impaired by reduced growth in the North. Therefore, the special situation of the pandemic has to be treated with care by economic policy actors in the global North, as far as government patent purchases are to be carried out.

Due to the special pandemic situation, from an economic point of view, it is indeed worth considering that the state or the international community of states purchase vaccine patents and complementary patents for vaccine production. This is because the pandemic situation means that people in the North of the world economy are little served by vaccine protection if vaccine protection in the South is inadequate - or achieved only with a significant delay - with existing economic globalization and international freedom of travel - as was normal in pre-corona pandemic times.

The Max Planck Institute in Magdeburg already pointed out in May 2020 that it is not only vaccine development which is a challenge, but vaccine production as well (MAX PLANCK INSTITUTE, 2020). The enormous quantities of vaccine needed to vaccinate almost the entire global population of over 7.5 billion people mean that rapid vaccination can only be achieved globally if, on the one hand, new production facilities are built quickly and existing production facilities are expanded or retooled. This is likely to prove impossible unless producers and suppliers from emerging countries are also comprehensively involved in corresponding production activities. Incidentally, this does not preclude vaccine-producing companies from industrialized countries from increasingly making direct investments in the pharmaceutical sector in such countries and, in this context, training workers in the host countries in a special way for vaccine production - very high-quality standards are generally required here.

There are initiatives, for example, by the WHO, the EU and private foundations, to provide funding for the purchase of coronavirus vaccines for developing countries or relatively poor countries; of particular importance is the global GAVI initiative or the COVAX consortium, which in the first week of February unveiled an initial plan to distribute 340 million AstraZeneca-Oxford vaccine doses to more than 70 countries with low per capita incomes (GAVI, 2021); the list of countries (see Appendix) includes a group of "self-pay" countries and a group that has virtually no budget for vaccine purchases. The number of vaccine doses should be sufficient to vaccinate at least health-sector workers, but the number of vaccine doses is just enough to vaccinate 170 million people initially; there is also an additional - manageable - number of vaccine doses from Biontech/Pfizer, although the strong cooling requirements are likely to be a barrier to vaccinations in a number of developing countries. The funds raised by the end of 2020 are unlikely to be sufficient to ensure the rapid widespread availability of vaccines and herd immunity in developing countries. Nevertheless, it should be noted that China and India, two very large emerging economies, are each active in the field of vaccine production - with vaccines they have developed themselves - and are also supplying vaccine doses to poorer countries with special conditions on a substantial scale in the medium term as part of a new international vaccine diplomacy effort. The US, UK and EU, as well as Switzerland and Norway, will also offer significant numbers of vaccine doses to developing countries at special rates by the end of 2021 as part of their vaccine diplomacy strategy. The political competition for influence of the US, EU, UK, China, Russia and India will help poor countries getting vaccines, however, it is not clear how big the amount of doses to be expected really is. One cannot rule out that a joint G20 provision effort for poor countries in the end generates a smaller amount of vaccine doses for poor countries in Africa, Latin America and Asia than the "free political competition" would have yielded.

A special possibility to accelerate vaccine production would be the introduction of an Open Innovation approach, open innovation regimes have already had a considerable positive effect on innovation dynamics in certain areas in the past (VON HIPPEL, 2005): Here, interested companies from all over the world - or a broad group of possible vaccine-producing countries - would be given patent-free access to the knowledge behind both the novel vaccine and the production process, which may also be patent-protected in the normal case. In the case of open innovation, there is then a particular opportunity for countries that have not previously produced vaccines to emerge as new vaccine producers. This helps with regard to the goal of rapidly achieving global herd immunity, but at the same time reduces future market shares and the profits of pharmaceutical companies in the North of the global economy: This will cause both future real wages and future returns in the pharmaceutical sector in the global North to decline or be dampened in terms of growth. There is therefore a conflict of objectives between rapid pandemic control and securing income and prosperity in the northern part of the global economy, whereby countries with pharmaceutical production such as the industrialized countries, as well as India and China, are likely to have reservations about open innovation - at any rate, they are likely to point to their special interests as R&D and production locations in the pharmaceutical sector.

5. Policy Conclusions

The coronavirus pandemic situation of 2020/21 is difficult overall, as there is a risk of recurring pandemic situations based on a mutated virus if vaccinations cannot be carried out sufficiently quickly in the South of the global economy. At the same time, there is the problem that relatively slow-paced vaccination campaigns in some OECD countries - especially in the EU - delay the economic upswing in industrialized countries and thus also impair economic exports or expansion opportunities in developing countries; in countries where people live at the subsistence level, this increases the risk that the number of deaths from hunger in the global South will rise. In the medium term, OECD countries will also see a renewed increase in immigration and refugee pressure from the global South.

There are five important key points for policy actors to consider:

- The faster the progress in vaccination, the stronger the economic upswing will be, which will also be accompanied internationally by increased growth in trade and direct investment.

- In countries with slow progress in terms of vaccinations, temporary lockdowns are worth considering; even more so, conservative epidemic control measures – such as mask-wearing, broad testing approaches, and enforceable quarantine regimes; the latter may include digital reporting apps for people in quarantine, and the use of such an app should be linked to financial incentives.

- It is urgent to establish G20 cooperation on immunization in the global North and South. This should include a G20 meeting at the level of health ministers on a monthly basis, with WHO playing a major role in the meeting, and the development of models of North-South economic linkages, taking into account the progress of immunization in the North and South of the global economy (for a simple approach, see the Annex).

- In all countries, regional relaxation concepts can apply to a respective region *i*, taking neighboring regions *j* into account. For border regions of a country, the incidence and R-values of neighboring foreign regions should also be taken into account. In regions with low test frequencies, it should be the case that below an R-value of significantly less than 1, no automatic relaxation steps should take place in the event of a lockdown. If, on the other hand, the R-value regionally is below 0.9, for example, an automatic relaxation can be introduced on the basis of a simple formula: Namely, by performing an *i*-value calculation supplemented by *j*-values, i.e. an "Adjusted Regional Incidence" or ARI (adjusted for the presence of old people's homes and nursing homes, for which special testing requirements usually exist on the part of the state) and linking this ARI additively with a weighted indicator for test quality - defined as 1-test frequency. The indicator can be defined such that if the total indicator $hARI + h'(1-T)$ is reached, the critical indicator value is 1; if a region is below 1, then an automated predefined lockdown sequence from lockdown occurs.

- The Adjusted Regional Incidence indicator gives each region meaningful incentives to push down the respective ARI in cooperation with neighboring regions. A high testing frequency can be considered indispensable from a theoretical point of view – at least until herd immunity is achieved (it is incomprehensible that Germany had not created a comprehensive testing network throughout the country by the end of 2020; in essence, one should have followed Tübingen as a model city with great success in reducing incidence through a clever regional testing concept). As the tests become better and cheaper over time, broad coronavirus testing concepts should also be feasible in emerging and developing countries.

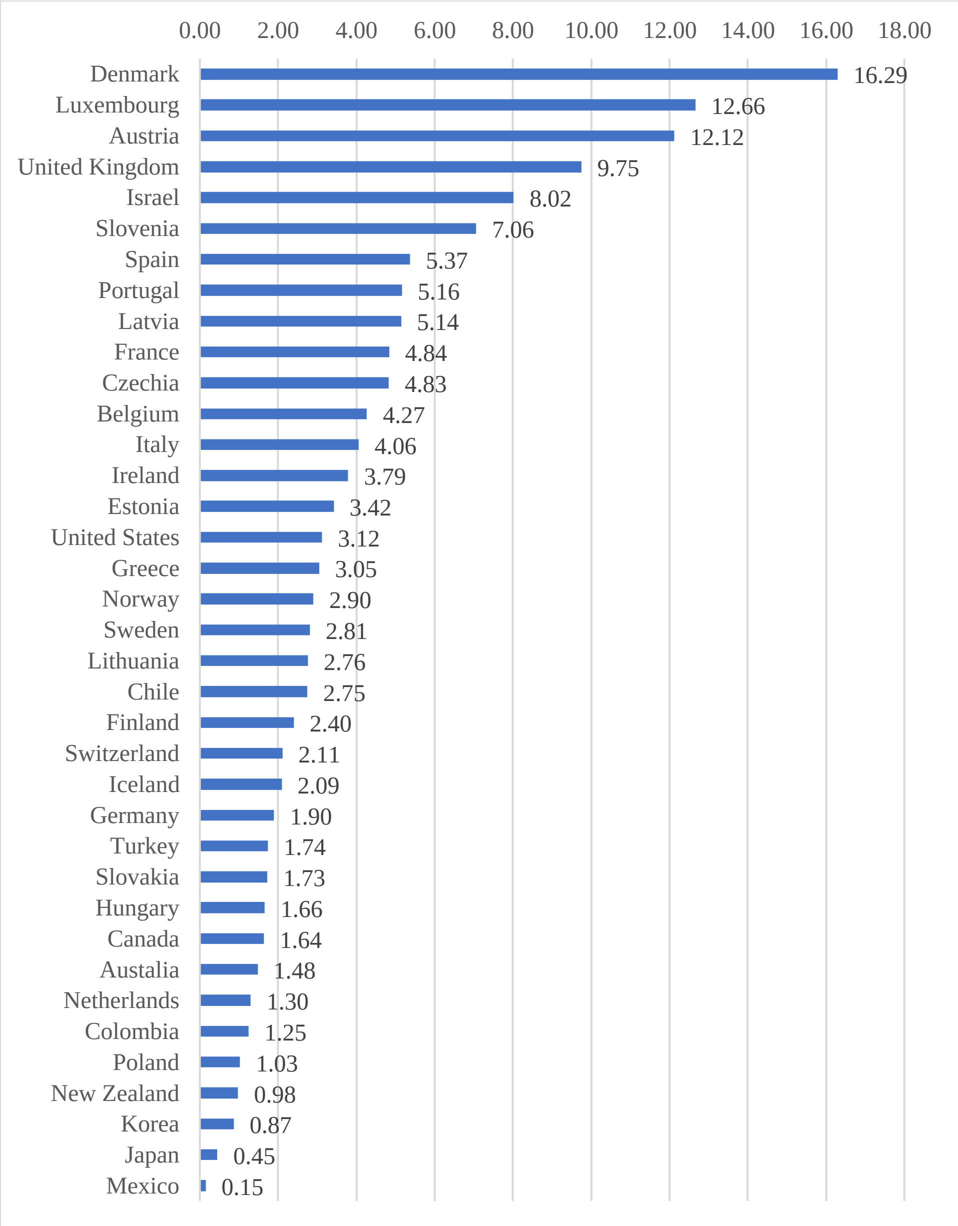
Policymakers in all countries across the world are challenged to first counteract the spread of the virus through meaningful measures, including mask-wearing and social-distancing, but also comprehensive testing & quarantine strategies, for which GRIES/WELFENS (2021) have developed proposals. Amongst OECD countries, Denmark is a leader in testing frequency: In 2020, the ratio of testing frequencies in Denmark to Germany was 4.5:1, in January 2021 it was 9:1, which is just the opposite of the development that seems necessary for Germany in the middle of a lockdown period. If the test frequency for everyone is increased to one test per week, then lockdowns can be dispensed with according to Gries and Welfens (2021). Incidentally, the case of quarantine rules not being adequately enforced by authorities in important fields can be seen as very problematic; for example, at the beginning of February 2021, there were reports on the German TV show Kontraste that at Berlin airport, arrivals from high-risk countries are by no means sensibly and strictly informed of the rules to be observed upon landing - many of these travelers simply take the next bus/subway/train connection on their trip home, which means a potential ‘super spreader’ risk. Here, you can see inconsistencies undermining an important part of corona policy in Germany.

Extensive experience from a good policy mix of mask-wearing, observing distancing rules plus testing & quarantine strategies - including modern digital contact tracing - is available from Taiwan amongst others. Testing & quarantine strategies are absolutely necessary on a broad scale until comprehensive vaccination capabilities are in place. Even without vaccination, the number of corona-related deaths in Taiwan in 2020 was only seven, out of a population of 24 million. Accordingly, based on Taiwan’s death incidence, the US and EU would have recorded only about 130 and 160 COVID-19 related deaths, respectively. However, these numbers are not very realistic for the United States or the European Union because there is relatively little epidemic experience in the US and the EU when compared with Asia, and because Taiwan’s insularity probably also provided better international compartmentalization opportunities with regard to the movement of people than either the EU or the US.

In terms of testing frequencies, Denmark is clearly leading amongst OECD countries at the beginning of February 2021, where testing frequency is almost nine times higher than in Germany – here, Germany is now even further behind than the annual average for 2020. Leading countries in terms of testing frequency at the beginning of February 2021 besides Denmark are Luxembourg, Austria, the UK, Israel and Slovenia.

Corona test intensities by country

Fig. 6: Daily COVID-19 testing per 1,000 individuals (7-day smoothed average; as of 08/02/21).



Source: Own illustration; data from Our World in Data

Note: Data shown is the latest available as of 08.02.21 (data range from January 24 (Netherlands) to February 5 (e.g. Latvia, Hungary, Korea)). For most of the selected countries, data are updated through Feb. 2. Since not all countries report test data on a daily basis, tests are assumed to have changed equally on a daily basis during the periods when data were not reported. This results in a full set of daily values that are then averaged over a rolling 7-day window.

Global perspectives

On the basis of the figures available in February 2021, there is no sign of a globally efficient vaccination campaign. Therefore, one should consider the following on the part of the policy in the South and/or in the North of the world economy:

- There are measures like mask-wearing and social distancing regulations as well as testing & quarantine, which allow to suppress the epidemic in a classic way: The countries in the South of the world economy should pay strong attention to this; but also the countries in the North at least until herd immunity is reached. With a slow start of vaccinations, OECD countries are at risk of a new pandemic in the medium term - not least stimulated by possible coronavirus mutations in the South of the world economy.

- OECD countries would be well advised to consider the disclosure of vaccine patents and vaccine production patents: With the purchase of patents at a meaningful compensation price by the G20 - this group of countries represents about 70 percent of the world economy in terms of output - a massive acceleration of importation could be achieved by involving more countries or companies in the production of vaccines.

- It would be useful to use market design approaches to agree optimal contract terms with vaccine producers from the perspective of the global community of nations. Initially - in the first quarters of vaccination programs - prices paid for vaccine doses should be significantly higher than, say, in the last quarter of the first year of vaccination; and when national herd immunity has been achieved, the level of prices should be significantly reduced. A bonus payment from the G20 countries should be given to those ten countries among the poorest 20 that have demonstrably achieved herd immunity the fastest. Offering such a bonus will result in all 20 countries achieving herd immunity faster than if the “speed premium” did not exist.

While there are good arguments for moving somewhat faster in terms of vaccination in the global North than in the developing world, the lower average age of the population in the latter group of countries leads to a partial prioritization of (older) people in countries with a high average age. Mortality from COVID-19 infection depends partly on the age group affected, but also on influencing factors such as obesity - in OECD countries - and the presence of pre-existing conditions (BRETSCHGER/GRIES/WELFENS/XIONG, 2020). However, it is essential to bring the vast majority of poorer countries on board with vaccination as early as the first half of 2021; South Africa indicated in January 2021 that it had ordered vaccines for 10 percent of the population and was working toward 65 percent vaccination coverage (GOVERNMENT OF SOUTH AFRICA, 2021). A coordinated approach, for example within the framework of the G20 - and in addition via the World Health Organization (WHO) - is indispensable for successful pandemic control. A G20 cooperation approach is likely to be able to act more quickly than the large number of WHO member countries because of the manageable number of countries involved. Indeed, rapid international cooperation steps in epidemic response are urgent in the context of a pandemic.

To the extent that countries want licensed production of new vaccines, appropriate compensation of the companies concerned for the patent value must be agreed multilaterally. Economic conflicts of interest between vaccine-producing countries and other countries are inevitable; this amounts to a North-South conflict of interest in the context of the pharmaceutical and chemical industries. The issue would be less clearly a North-South problem if there were also vaccine production on a larger scale in emerging countries. In view of the large world population and with a view to future pandemic risks, it would make strategic sense - also from the perspective of the countries in the North - that a minimum level of vaccine production should also be realized in emerging countries outside the two major vaccine-producing countries of India and China. If mutations result in a new pandemic, there is a high risk that the global economic upswing of 2021 will collapse in the medium term.

If the proposed points on the part of the G20 countries' policy are implemented, the global coronavirus vaccination program will likely be successfully completed before the end of 2022. But this should be the concern of the global community. The cooperation of medical and economic experts is, by the way, very important for a speedy, successful overcoming of the current pandemic.

Policy perspectives on EU procurement problems.

The limited autonomy of the European Commission may partly explain the strangely slow EU vaccine procurement process, in which apparently Eastern European EU member countries in particular showed little willingness to grant adequate prices to vaccine producers and, moreover, there were clear reservations on the part of these countries against novel mRNA vaccines, since mRNA represented an innovative vaccination approach and, furthermore, because relatively demanding cooling requirements had to be observed in vaccine logistics. In terms of vaccine procurement, the EU27 has shown that the EU design – namely, the lack of a political union as the basis for a rapid response to crises - is indicative of significant weaknesses compared to the US and UK, which in the end amounts to an unnecessarily high number of COVID-19 infections and COVID-19 deaths in the EU, as well as severely damaging recovery across the EU. There is little traceable political accountability in any of this. In a historic probationary period, i.e., following BREXIT, the European Union has shown great weakness in vaccine procurement. Considering the fact that the EU recorded 400,000 corona deaths in 2020, and that each month of vaccination delay costs 1 percent in EU economic output, compared to the UK this should mean a foreseeable three-month lag for the EU in completing corona vaccinations:

- At least 50,000 unnecessary EU deaths are conceivable, based on the figure of 400,000 COVID-19 deaths in the EU in 2020 and considering vaccination priorities in the EU (if one wanted to actuarially value one human life at €1 million, this would correspond to a loss of €50 billion, which immediately shows the dubiousness of those actors in Brussels or the EU, respectively, who mainly relied on acquiring relatively cheap vaccines in EU procurement);

- about €400 billion of the loss in GDP results from an EU real income dampening effect of 3 percent; for Germany it is about a €90 billion loss in income, which also means a €36 billion loss in government revenue at a tax and social security contribution ratio of 40 percent. The EU itself lost around €4.5 billion in revenue, assuming a 1.1 percent EU government expenditure ratio;

- the real income loss to the US from unnecessary EU growth dampening is likely to be at least €40 billion; the income dampening effects indirectly triggered by the EU in other world regions are likely to be a further €60 billion. This has an additional negative repercussive effect on EU national income, which is likely to be around minus €10 billion;

- the number of additional cases of infection in the EU and in the world - due to infections originating in the EU from people who would have been vaccinated long ago in the case of a turbo vaccination program and therefore would likely have been no longer infectious - is likely to affect more than five million people directly, resulting in considerable additional health costs and also unnecessary production losses; if one assumes €1,000 in additional costs (health costs and production loss effect) per infected person, economic losses of €5 billion are to be estimated here as corresponding vaccination delay costs;

- the EU lag of about three months in terms of vaccinations means that the minimum vaccination rate in the EU and worldwide will increase in the wake of additional virus mutations: Assuming a 5 percent additional minimum vaccination coverage in this context, and assuming two required vaccinations per person and a dose price of €15 per capita, additional vaccination costs worldwide of €11 billion have been caused by the slow EU procurement. The European Commission itself helped collect €8 billion for COVID-19 drugs and COVID-19 vaccines in a major vaccine budget collection drive for poorer countries, so the inadequate EU strategy arguably negates this aid effect. In addition, the unnecessarily high EU infection figures from the first half of 2021 (and probably also from the 3rd quarter) also lead to increased infection figures or deaths in the global South via international contagion effects, the damage of which is difficult to quantify or estimate economically;

- the aforementioned roughly estimated vaccine procurement delay costs for the EU thus amount to well over €600 billion (€676 billion; which converts to €1,500 in costs per EU citizen). From an economic and medical point of view, the EU vaccine procurement campaign has therefore been completely irresponsible and negligent. It is not foreseeable that those politically responsible for this EU fiasco - for which the national governments of some EU countries are also massively culpable - will be held accountable in any way.

The claim from parts of the European Commission that the long EU negotiation process was necessary in order to contractually anchor liability issues at the expense of vaccine producing companies is a strange view, which in fact reveals a low political priority to achieve a rapid vaccine supply for the EU population. The European Parliament apparently exerted pressure on the Commission to solve the liability issues at the expense of the vaccine providers. The economic logic of this approach has not been understood by the relevant players in EU politics, because shifting liability to a large extent onto the producers naturally means that supply prices will rise and supply volumes will fall - because the suppliers will now add the risk costs to the research costs and the production costs when calculating prices.

In the US, for the past 15 years, the PREP Act represents a law that places pharmaceutical companies in a relatively good position in terms of liability when it comes to new drugs or vaccines in the context of combating an acute medical emergency in the United States. The United States therefore has a better legislative environment when it comes to incentives for companies to develop innovative vaccines and drugs. The idea in parts of the EU that the state should not assume liability risks for novel vaccines and medicines in a medical emergency is detrimental to innovation and therefore epidemic-promoting - in other words, is detrimental to the protection of the health of the population. A public debate is obviously urgently needed here.

Had Germany, France, Italy, and the Netherlands, as well as some other western EU countries, procured vaccines as an independent group (e.g., as a Eurozone group), vaccine procurement would have been much faster for these countries than it was for the EU as a whole. With a sound concept for EU vaccine procurement, the EU could well have realized benefits as a procurement institution, but in the absence of any thoughtful concept, the EU’s vaccine procurement approach was a historic policy failure by the European Commission, which was ultimately responsible.

This casts a bad light not only on the European Commission, but also on the role of Eastern European countries and also Spain (DEUTSCH/WHEATON, 2021); these countries in particular have in effect significantly slowed down the EU procurement process and the vaccination campaigns of the EU27 countries, which in turn also puts countries in the global South at a significant disadvantage in terms of epidemic protection and economic development opportunities.

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Appendix 1: Population figures for Africa

Tab. 3: Population figures for Africa and other selected countries

Africa (selected countries)	Population as of 2019*
Nigeria	200,963,599
Egypt, Arab Rep.	100,388,073
South Africa	58,558,270
Algeria	43,053,054
Morocco	36,471,769
Tunisia	11,694,719
Libya	6,777,452
Rest of Africa	*859,821,163*
Total	**1,317,728,099**
Arabian Peninsula	
Saudi Arabia	34,268,528
Yemen, Rep.	29,161,922
United Arab Emirates	9,770,529
Oman	4,974,986
Kuwait	4,207,083
Qatar	2,832,067
Bahrain	1,641,172
Total	**86,856,287**

Source: World Bank (2021) World Development Indicators

Note: All population figures for 2019 except for Eritrea where the last available population figure is for 2011. Coverage for Africa includes 54 countries according to UN classifications

Appendix 2: COVAX country list with intended vaccine dose distribution (as of February 5, 2021).

Tab. 4: COVAX country list with intended vaccine dose distribution (as of February 5, 2021).

Participant	*# Doses - AZ/SII (indicative distribution)*	*# Doses - AZ/SKBio (indicative distribution)*	*# Doses - Pfizer-BioNTech (exceptional allocation)*	*Participant*	*# Doses - AZ/SII (indicative distribution)*	*# Doses - AZ/SKBio (indicative distribution)*	*# Doses - Pfizer-BioNTech (exceptional allocation)*
Afghanistan	*3,024,000*	*-*	*-*	*Malawi*	*1,476,000*	*-*	*-*
Albania	*-*	*141,600*	*-*	*Malaysia*	*-*	*1,624,800*	*-*
Algeria	*-*	*2,200,800*	*-*	*Maldives*	*108,000*	*-*	*5,850*
Andorra	*-*	*26,400*	*-*	*Mali*	*1,572,000*	*-*	*-*
Angola	*2,544,000*	*-*	*-*	*Marshall Islands*	*-*	*24,000*	*-*
Antigua & Bar.	*-*	*40,800*	*-*	*Mauritania*	*360,000*	*-*	*-*
Argentina	*-*	*2,275,200*	*-*	*Mauritius*	*-*	*100,800*	*-*
Armenia	*-*	*146,400*	*-*	*Mexico*	*-*	*6,472,800*	*-*
Azerbaijan	*-*	*506,400*	*-*	*Micronesia*	*-*	*48,000*	*-*
Bahamas	*-*	*100,800*	*-*	*Moldova*	*-*	*156,000*	*24,570*
Bahrain	*-*	*100,800*	*-*	*Monaco*	*-*	*7,200*	*-*
Bangladesh	*12,792,000*	*-*	*-*	*Mongolia*	*-*	*163,200*	*25,740*
Barbados	*-*	*100,800*	*-*	*Montenegro*	*-*	*84,000*	*-*
Belize	*-*	*100,800*	*-*	*Morocco*	*-*	*1,881,600*	*-*
*Benin**	*936,000*	*-*	*-*	*Mozambique*	*2,424,000*	*-*	*-*
Bhutan	*108,000*	*-*	*5,850*	*Myanmar*	*4,224,000*	*-*	*-*
Bolivia	*900,000*	*-*	*92,430*	*Namibia*	*-*	*127,200*	*-*
Bosnia & Heart.	*-*	*153,600*	*23,400*	*Nauru*	*-*	*7,200*	*-*
Botswana	*-*	*117,600*	*-*	*Nepal*	*2,256,000*	*-*	*-*
Brazil	*-*	*10,672,800*	*-*	*New Zealand*	*-*	*249,600*	*-*
Brunei Darus.	*-*	*100,800*	*-*	*Nicaragua*	*504,000*	*-*	*-*

Burkina Faso	*1,620,000*	*-*	*-*	*Niger*	*1,872,000*	*-*	*-*
Cabo Verde	*108,000*	*-*	*5,850*	*Nigeria*	*16,008,000*	*-*	*-*
Cambodia	*1,296,000*	*-*	*-*	*N. Macedonia*	*-*	*103,200*	*-*
Cameroon	*2,052,000*	*-*	*-*	*Oman*	*-*	*254,400*	*-*
Canada	*-*	*1,903,200*	*-*	*Pakistan*	*17,160,000*	*-*	*-*
Cent. Afr. Rep.	*372,000*	*-*	*-*	*Panama*	*-*	*216,000*	*-*
Chad	*1,272,000*	*-*	*-*	*Papua New Guin.*	*684,000*	*-*	*-*
Chile	*-*	*957,600*	*-*	*Paraguay*	*-*	*357,600*	*-*
Colombia	*-*	*2,553,600*	*117,000*	*Peru*	*-*	*1,653,600*	*117,000*
Comoros	*108,000*	*-*	*-*	*Philippines*	*-*	*5,500,800*	*117,000*
Congo, Dem. Rep.	*6,948,000*	*-*	*-*	*Qatar*	*-*	*144,000*	*-*
Congo, Rep.	*420,000*	*-*	*-*	*Rep. of Korea*	*-*	*2,596,800*	*117,000*
Costa Rica	*-*	*254,400*	*-*	*Rwanda*	*996,000*	*-*	*102,960*
Cote d'Ivoire	*2,040,000*	*-*	*-*	*Samoa*	*-*	*79,200*	*-*
Djibouti	*108,000*	*-*	*-*	*Sao Tome & Princ.*	*96,000*	*-*	*-*
Dominica	*-*	*28,800*	*-*	*Saudi Arabia*	*-*	*1,747,200*	*-*
Dominican Rep.	*-*	*542,400*	*-*	*Senegal*	*1,296,000*	*-*	*-*
Ecuador	*-*	*885,600*	*-*	*Serbia*	*-*	*345,600*	*-*
Egypt	*-*	*5,138,400*	*-*	*Sierra Leone*	*612,000*	*-*	*-*
El Salvador	*-*	*324,000*	*51,480*	*Singapore*	*-*	*288,000*	*-*
Eswatini	*108,000*	*-*	*-*	*Solomon Islands*	*108,000*	*-*	*-*
Ethiopia	*8,928,000*	*-*	*-*	*Somalia*	*1,224,000*	*-*	*-*
Fiji	*-*	*100,800*	*-*	*South Africa*	*-*	*2,976,000*	*117,000*
Gambia, The	*180,000*	*-*	*-*	*South Sudan*	*864,000*	*-*	*-*
Georgia	*-*	*184,800*	*29,250*	*Sri Lanka*	*1,692,000*	*-*	*-*
Ghana	*2,412,000*	*-*	*-*	*Saint Kitts & Nevis*	*-*	*21,600*	*-*
*Grenada**	*-*	*45,600*	*-*	*Saint Lucia**	*-*	*74,400*	*-*
Guatemala	*-*	*847,200*	*-*	*St. Vincent*	*-*	*45,600*	*-*
Guinea	*1,020,000*	*-*	*-*	*Sudan*	*3,396,000*	*-*	*-*
Guinea-Bissau	*144,000*	*-*	*-*	*Suriname*	*-*	*79,200*	*-*

Guyana	*-*	*100,800*	*-*	*Syria***	*1,020,000*	*-*	*-*
*Haiti**	*876,000*	*-*	*-*	*Tajikistan*	*732,000*	*-*	*-*
Honduras	*-*	*496,800*	*-*	*Timor-Leste*	*-*	*100,800*	*-*
India	*97,164,000*	*-*	*-*	*Togo*	*636,000*	*-*	*-*
Indonesia	*-*	*13,708,800*	*-*	*Tonga*	*-*	*43,200*	*-*
Iran	*-*	*4,216,800*	*-*	*Trinidad and Tob.*	*-*	*100,800*	*-*
Iraq	*-*	*2,018,400*	*-*	*Tunisia*	*-*	*592,800*	*93,600*
Jamaica	*-*	*146,400*	*-*	*Tuvalu*	*-*	*4,800*	*-*
Jordan	*-*	*511,200*	*-*	*Uganda*	*3,552,000*	*-*	*-*
Kenya	*4,176,000*	*-*	*-*	*Ukraine*	*-*	*2,215,200*	*117,000*
Kiribati	*-*	*48,000*	*-*	*Uruguay*	*-*	*172,800*	*-*
Korea, Dem. Rep.	*1,992,000*	*-*	*-*	*Uzbekistan*	*2,640,000*	*-*	*-*
Kosovo	*-*	*100,800*	*-*	*Vanuatu*	*-*	*100,800*	*-*
Kyrgyz Rep.	*504,000*	*-*	*-*	*Venezuela*	*-*	*1,425,600*	*-*
Lao PDR	*564,000*	*-*	*-*	*Vietnam*	*-*	*4,886,400*	*-*
Lebanon	*-*	*340,800*	*-*	*West Bank/Gaza*	*-*	*240,000*	*37,440*
Lesotho	*156,000*	*-*	*-*	*Yemen, Rep.*	*2,316,000*	*-*	*-*
Liberia	*384,000*	*-*	*-*	*Zambia*	*1,428,000*	*-*	*-*
Libya	*-*	*343,200*	*-*	*Zimbabwe**	*1,152,000*	*-*	*-*
				Non-UN Members	*-*	*1,303,200*	*-*

Source: GAVI (2021), Interim Distribution Forecast https://www.gavi.org/sites/default/files/covid/covax/COVAX-Interim-Distribution-Forecast.pdf
Note: *Participation pending final evaluation of vaccine application submitted to COVAX facility. **Additional doses will be allocated for distribution by UN partners as required by country context.

Appendix 3: Urbanity population density

Tab. 5: Urbanity population density 2019 (in % of total population), countries of the world (World Bank)

Bermuda	100.00	Saudi Arabia	84.07	Estonia	69.05	Syria	54.82	Grenada	36.40
Cayman Isl.	100.00	UK	83.65	Mongolia	68.54	Mauritania	54.51	Lao PDR	35.65
Gibraltar	100.00	Bahamas	83.13	Latvia	68.22	Romania	54.08	Sudan	34.94
Hong Kong SAR	100.00	Norway	82.62	Panama	68.06	Slovak Rep.	53.73	Tanzania	34.50
Kuwait	100.00	US	82.46	Lithuania	67.86	Trin. & Tob.	53.19	India	34.47
Macau SAR	100.00	Dominican Rep.	81.83	Congo, Rep.	67.37	Isle of Man	52.74	Zimbabwe	32.21
Monaco	100.00	Canada	81.48	Montenegro	67.15	St. Vincent	52.61	Barbados	31.16
Nauru	100.00	Korea, Rep.	81.43	South Africa	66.86	Turkmenistan	52.05	Timor-Leste	30.95
Singapore	100.00	Colombia	81.10	Cyprus	66.81	Liberia	51.62	Channel Isl.	30.93
Sint Maarten	100.00	France	80.71	Cabo Verde	66.20	Guatemala	51.44	Myanmar	30.85
Qatar	99.19	Spain	80.57	Angola	66.18	Cote d'Ivoire	51.24	St. Kitts & N.	30.80
Belgium	98.04	Palau	80.47	Suriname	66.10	Nigeria	51.16	Burkina Faso	29.98
San Marino	97.37	Mexico	80.44	Portugal	65.76	Namibia	51.04	Comoros	29.16
Virgin Islands (US)	95.83	Libya	80.39	Ecuador	63.99	Thailand	50.69	Lesotho	28.59
Uruguay	95.43	Costa Rica	80.08	Ireland	63.41	Uzbekistan	50.43	Kenya	27.51
Guam	94.86	Greece	79.39	Armenia	63.22	Bosnia & Heart.	48.63	Tajikistan	27.31
Malta	94.68	Belarus	79.04	Tuvalu	63.22	British Virgin Isl.	48.12	Guyana	26.69
Iceland	93.86	Peru	78.10	Morocco	62.99	Benin	47.86	Afghanistan	25.75
Puerto Rico	93.58	Brunei Darus.	77.94	North Korea	62.13	Senegal	47.65	Vanuatu	25.39
Turks & Caicos Isl.	93.36	Djibouti	77.92	Gambia, The	61.93	Philippines	47.15	Antigua & B.	24.51
Israel	92.50	Marshall Isl.	77.42	French Poly.	61.90	Belize	45.87	Uganda	24.36
Argentina	91.99	Germany	77.38	Paraguay	61.88	Somalia	45.55	Solomon Isl.	24.21
Netherlands	91.88	Cuba	77.11	Albania	61.23	Congo, Dem. Rep.	45.05	Eswatini	23.98
N. Mariana Isl.	91.71	Malaysia	76.61	China	60.31	Zambia	44.07	Cambodia	23.81
Japan	91.70	W. Bank/Gaza	76.44	Poland	60.04	Guinea-Bissau	43.78	Chad	23.28
Luxembourg	91.22	Turkey	75.63	Georgia	59.04	Aruba	43.55	Tonga	23.11
Jordan	91.20	Iran	75.39	Nicaragua	58.76	Mali	43.14	Micronesia	22.81

Gabon	89.74	Bulgaria	75.35	Austria	58.52	Egypt	42.73	Ethiopia	21.23
Bahrain	89.39	Russia	74.59	N. Macedonia	58.21	Moldova	42.73	Nepal	20.15
Curacao	89.10	Czechia	73.92	Honduras	57.73	Sierra Leone	42.48	South Sudan	19.90
Lebanon	88.76	Switzerland	73.85	Kazakhstan	57.54	Togo	42.25	St. Lucia	18.75
Venezuela, RB	88.24	S. Tome & Prin.	73.60	Croatia	57.24	Faroe Islands	42.23	Sri Lanka	18.59
Denmark	87.99	Algeria	73.19	Seychelles	57.12	C.A.R.	41.77	Samoa	18.06
Andorra	87.98	El Salvador	72.75	Cameroon	56.97	Bhutan	41.61	Rwanda	17.31
Sweden	87.71	Equat. Guinea	72.63	Fiji	56.75	Mauritius	40.77	Malawi	17.17
Chile	87.64	Hungary	71.64	Ghana	56.71	Maldives	40.24	Niger	16.52
American Samoa	87.15	New Caledonia	71.10	Serbia	56.26	Madagascar	37.86	Liechtenstein	14.37
Greenland	87.05	Dominica	70.79	Haiti	56.19	Bangladesh	37.41	Burundi	13.37
Brazil	86.82	Italy	70.74	Azerbaijan	56.03	Yemen, Rep.	37.27	Papua New Guinea	13.25
UAE	86.79	Iraq	70.68	Indonesia	55.99	Pakistan	36.91		
New Zealand	86.62	Botswana	70.17	Jamaica	55.99	Vietnam	36.63		
Australia	86.12	Bolivia	69.77	World	55.71	Kyrgyz Republic	36.59		
Finland	85.45	Ukraine	69.47	Kiribati	54.84	Mozambique	36.53		
Oman	85.44	Tunisia	69.25	Slovenia	54.82	Guinea	36.50		

Source: Own illustration, World Bank data

Appendix 4: Immunization Progress in North and South as Affecting Real World Income

A supply-side and demand-side view of vaccination prospects is important, with the supply side or production potential in a two-country context (world economy) being considered here first. The focus here is on the global North on the one hand and the South on the other, as well as the world economy as a whole. In line with the Heckscher-Ohlin assumptions, it is assumed that production technology in the global North and in the South is the same and therefore ß=ß* applies (ß is the production elasticity of capital; * represents foreign variables/countries).

If we denote with v, or v* respectively, the share of the non-inoculated in the domestic country or economy) – in our example, the global North - and abroad (i.e., the South of the world economy), then with K for the capital stock, A for knowledge, L the labor force, and positive parameters ß, v' and v'' (0<ß<1), one can write the production function in the domestic economy as $Y= (1-v'v -v''v^*)K^{ß}(AL)^{1-ß}$; and in the foreign economy - assuming ß*=ß - as $Y^*= (1- v'^*v -v''^*v^*)K^{*ß}(A^*L^*)^{1-ß}$. It is assumed that the proportion of non-vaccinated persons at home is positively correlated with the number of infected and therefore non-working persons or deaths; with a similar correlation abroad, supply problems increase with the proportion of non-vaccinated persons abroad (the corresponding influencing parameters for the effective production potential at home are v' and v''). It is also assumed here that v'v + v''v* and v'*v + v''*v* are both less than 1 and that v'v+v''v*>v'*v+v''*v*; the economically dampening influence of the non-vaccination rates in the North of the world economy is thus stronger than in the South of the world economy, which is helped here by the lower average age of the population: the natural defenses of younger people are noticeably stronger on average than those of the elderly, who tend to have relatively weak immune systems. The real world income (with q*:=eP*/P as real exchange rate; e the nominal exchange rate, P* the price level abroad and P the price level at home) is Y'= Y + q*Y*, which can be written as Y'/Y = 1 + q*Y*/Y. If Y stands for a large country - in the economic sense - and Y* for a small country (thus also Y*q*/Y is close to zero), the approximate solution for the case that v'v + v''v* is close to zero and v'*v + v''*v* is close to zero holds:

1) $\ln Y'= \ln Y + q^*Y^*/Y = -v'v -v''v^* + ß\ln K + (1-ß)(\ln AL)$

$+ q^*[(1- v'^*v -v''^*v^*)/(1-v'v -v''v^*)](K^*/K)^{ß}(A^*L^*/(AL))^{1-ß}$

The square bracket expression is greater than 1. The partial derivatives of dlnY' with respect to dv and of dv* are:

2)

a) $d\ln Y'/dv=-v'+q^*\{[(v''v^*-1)v'^*+(1-v''^*v^*)v']/(v'v+v''v^*-1)^2\}(K^*/K)^{ß}(A^*L^*/(AL))^{1-ß}$

b) $d\ln Y'/dv^*= -v''+q^*\{[(v'v-1)v''^*+(1-v'^*v)v'']/(v''v^*+v'v-1)^2\}(K^*/K)^{ß}(A^*L^*/(AL))^{1-ß}$

Concerning the sign of the expressions at a) and b), note: The denominator of the fraction always positive, numerator:

(a) negative if: |(v”v*-1)v’*| > (1-v”*v*)v’;

The derivative is altogether negative, if the numerator < 0 and q*... <v’

(b) negative, if: |(v’v-1)v”*| > (1-v’*v)v”;

The derivative overall negative if numerator < 0 and q*... < v”

The effect of increased non-vaccination rates on world income is therefore likely to be negative, although this only affects the supply side of the global economy. Of course, this is even more true for the demand side; low vaccination rates mean high contagion risk, which dampens consumer demand and thus investment. Conversely, progress in the vaccination process, or moving closer to herd immunity, increases consumer confidence. Once a critical minimum growth in household and investor confidence is established in OECD countries, a confidence acceleration is likely to occur in advance of an acceleration in terms of economic recovery.

Appendix 5: Covid-19 mortality rates (108 countries following the country grouping in BRETSCHGER/GRIEG/WELFENS/XIONG, 2020); OECD and non-OECD countries ranked by mortality rates in descending order.

The 10 worst countries in the table below include Belgium, Slovenia, the UK, Czechia, Italy, Portugal, the US, Hungary, Spain, and Mexico, with Belgium's mortality rate 15 times that of Finland. Denmark's mortality rate is about half that of Germany, with Denmark's test rate in 2020 being about 4.5 times that of Germany. Japan, Australia, South Korea and New Zealand are, at the bottom of the table, in the exemplary range amongst OECD countries. India and Indonesia, as non-OECD countries, are about as high as Finland in terms of mortality rates.

Tab. 6: Selected Covid-19 cumulated Statistics for OECD Countries and Newly Industrializing Countries up to 9 February 2021; countries sorted by the Fatality Ratio in descending order

	No.	Location	Iso3	Total_cases	Total_deaths	Infection ratio per mln	Fatality ratio per mln
OECD 37	1	Belgium	BEL	728,334	21,472	62,844	1,853
	2	Slovenia	SVN	174,364	3,654	83,872	1,758
	3	United Kingdom	GBR	3,983,756	114,066	58,683	1,680
	4	Czechia	CZE	1,045,132	17,497	97,594	1,634
	5	Italy	ITA	2,655,319	92,002	43,917	1,522
	6	Portugal	PRT	770,502	14,557	75,564	1,428
	7	United States	USA	27,192,455	468,203	82,152	1,414
	8	Hungary	HUN	378,734	13,249	39,205	1,371
	9	Spain	ESP	3,005,487	63,061	64,282	1,349
	10	Mexico	MEX	1,946,751	168,432	15,099	1,306
	11	France	FRA	3,419,210	80,295	52,383	1,230
	12	Sweden	SWE	596,174	12,188	59,031	1,207
	13	Switzerland	CHE	536,516	9,687	61,992	1,119
	14	Colombia	COL	2,166,904	56,507	42,586	1,111
	15	Lithuania	LTU	187,421	2,972	68,847	1,092
	16	Poland	POL	1,556,685	39,360	41,131	1,040
	17	Chile	CHL	758,189	19,084	39,662	998
	18	Slovakia	SVK	265,807	5,382	48,686	986
	19	Luxembourg	LUX	52,022	600	83,105	959
	20	Austria	AUT	426,093	8,071	47,310	896
	21	Netherlands	NLD	1,023,779	14,629	59,748	854
	22	Ireland	IRL	204,940	3,752	41,504	760
	23	Germany	DEU	2,302,051	63,006	27,476	752
	24	Latvia	LVA	72,869	1,363	38,633	723
	25	Israel	ISR	703,719	5,216	81,303	603
	26	Greece	GRC	166,067	6,017	15,933	577
	27	Canada	CAN	815,487	20,914	21,607	554
	28	Denmark	DNK	203,104	2,245	35,065	388
	29	Estonia	EST	48,809	474	36,794	357

	30	Turkey	TUR	2,548,195	26,998	30,214	320
	31	Finland	FIN	48,407	703	8,737	127
	32	Norway	NOR	65,338	583	12,052	108
	33	Iceland	ISL	6,025	29	17,656	85
	34	Japan	JPN	408,550	6,601	3,230	52
	35	Australia	AUS	28,871	909	1,132	36
	36	SouthKorea	KOR	81,930	1,486	1,598	29
	37	New Zealand	NZL	2,324	25	482	5
	Total			60,576,320	1,365,289		
	Population weighted average					43,273	872
Non-OECD	38	Bosnia and Herzegovina	BIH	124,443	4,834	37,931	1,473
	39	Bulgaria	BGR	226,061	9,482	32,534	1,365
	40	Panama	PAN	328,476	5,531	76,128	1,282
	41	Croatia	HRV	235,756	5,224	57,428	1,273
	42	Brazil	BRA	9,599,565	233,520	45,162	1,099
	43	Argentina	ARG	1,993,295	49,566	44,104	1,097
	44	Romania	ROU	749,434	19,056	38,957	991
	45	Moldova	MDA	165,663	3,573	41,067	886
	46	Ecuador	ECU	259,783	15,086	14,724	855
	47	Georgia	GEO	263,057	3,306	65,943	829
	48	South Africa	ZAF	1,479,253	46,869	24,942	790
	49	Iran	IRN	1,481,396	58,625	17,637	698
	50	Tunisia	TUN	218,564	7,332	18,493	620
	51	Serbia	SRB	411,855	4,154	60,526	610
	52	Ukraine	UKR	1,293,892	25,022	29,586	572
	53	Costa Rica	CRI	197,852	2,698	38,839	530
	54	Eswatini	SWZ	16,288	610	14,039	526
	55	Russia	RUS	3,953,970	76,347	27,094	523
	56	Albania	ALB	87,528	1,488	30,415	517
	57	Paraguay	PRY	139,819	2,862	19,603	401
	58	Azerbaijan	AZE	231,362	3,163	22,819	312
	59	Oman	OMN	136,187	1,536	26,669	301
	60	Suriname	SUR	8,710	163	14,847	278
	61	Dominican Republic	DOM	224,538	2,864	20,699	264
	62	El Salvador	SLV	56,653	1,701	8,734	262
	63	Cape Verde	CPV	14,479	137	26,042	246
	64	Cyprus	CYP	31,959	214	36,487	244
	65	Kuwait	KWT	172,996	975	40,509	228
	66	Morocco	MAR	476,125	8,424	12,899	228
	67	Bahrain	BHR	108,807	387	63,945	227
	68	Kyrgyzstan	KGZ	85,171	1,433	13,055	220
	69	Saudi Arabia	SAU	370,987	6,410	10,656	184
	70	Kazakhstan	KAZ	246,474	3,127	13,127	167
	71	Namibia	NAM	35,201	377	13,854	148
	72	Uruguay	URY	46,153	506	13,286	146
	73	Jamaica	JAM	17,701	359	5,978	121
	74	Indonesia	IDN	1,174,779	31,976	4,295	117
	75	India	IND	10,858,371	155,252	7,868	113
	76	Philippines	PHL	540,227	11,296	4,930	103
	77	Lesotho	LSO	9,718	207	4,536	97
	78	United Arab Emirates	ARE	332,603	947	33,629	96
	79	Egypt	EGY	170,780	9,751	1,669	95
	80	Qatar	QAT	155,002	253	53,800	88
	81	Botswana	BWA	24,435	179	10,391	76
	82	Seychelles	SYC	1,695	7	17,236	71

83	Nepal	NPL	272,215	2,047	9,343	70
84	Barbados	BRB	1,814	20	6,312	70
85	Algeria	DZA	109,559	2,924	2,498	67
86	Djibouti	DJI	5,959	63	6,031	64
87	Pakistan	PAK	557,591	12,128	2,524	55
88	Bangladesh	BGD	538,765	8,229	3,271	50
89	Zambia	ZMB	64,610	881	3,514	48
90	Senegal	SEN	29,245	700	1,747	42
91	Kenya	KEN	102,048	1,789	1,898	33
92	Malaysia	MYS	248,316	909	7,672	28
93	Cuba	CUB	34,064	244	3,007	22
94	Uzbekistan	UZB	79,204	621	2,366	19
95	Sri Lanka	LKA	71,211	370	3,326	17
96	Ghana	GHA	73,003	482	2,349	16
97	Mauritius	MUS	594	10	467	8
98	Brunei	BRN	182	3	416	7
99	Singapore	SGP	59,732	29	10,210	5
100	Benin	BEN	4,193	55	346	5
101	China	CHN	100,475	4,824	70	3
102	Fiji	FJI	56	2	62	2
103	Thailand	THA	23,746	79	340	1
104	Mongolia	MNG	2,174	2	663	1
105	Vietnam	VNM	2,064	35	21	0
106	Tanzania	TZA	509	21	9	0
107	Cambodia	KHM	476		28	
108	Laos	LAO	45		6	
Total			41,138,913	853,296		
Population weighted average					18,107	310

Source: Own representation of data available from Our World in Data

Appendix 6: Median age of the population (2020)

Tab. 7: Median age of the population in years 2020, by country; countries ranked by highest to lowest media age

Country	Years	Country	Years	Country	Years	Country	Years
Japan	48.4	N. Macedonia	39.1	Maldives	29.9	Tonga	22.4
Italy	47.3	Montenegro	38.8	Indonesia	29.7	Equatorial Guinea	22.3
Martinique	47.0	China	38.4	Panama	29.7	Samoa	21.8
Portugal	46.2	US	38.3	Venezuela	29.6	Namibia	21.8
Germany	45.7	Georgia	38.3	Lebanon	29.6	Ghana	21.5
Greece	45.6	Ireland	38.2	Morocco	29.5	Vanuatu	21.1
Lithuania	45.1	New Zealand	38.0	Mexico	29.2	Iraq	21.0
Spain	44.9	Australia	37.9	Suriname	29.0	Timor-Leste	20.8
China, Hong Kong SAR	44.8	Moldova	37.6	Myanmar	29.0	Palestine	20.8
Bulgaria	44.6	Iceland	37.5	Libya	28.8	Eswatini	20.7
Slovenia	44.5	Mauritius	37.5	Algeria	28.5	Comoros	20.4
Puerto Rico	44.5	Cyprus	37.3	India	28.4	Yemen	20.2
Croatia	44.3	Kuwait	36.8	W. Sahara	28.4	Kenya	20.1
Latvia	43.9	Albania	36.4	Mongolia	28.2	Mauritania	20.1
Republic of Korea	43.7	Trinidad & Tobago	36.2	Bhutan	28.1	Mayotte	20.1
Guadeloupe	43.7	Réunion	35.9	Dominican Rep.	28.0	Rwanda	20.0
Austria	43.5	Uruguay	35.8	Ecuador	27.9	Solomon Isl.	19.9
Hungary	43.3	Armenia	35.4	Fiji	27.9	Sudan	19.7
Netherlands	43.3	Chile	35.3	Uzbekistan	27.8	Madagascar	19.6
Czechia	43.2	D.P.R. Korea	35.3	South Africa	27.6	Ethiopia	19.5
Romania	43.2	Saint Lucia	34.5	Cabo Verde	27.6	Liberia	19.4
Finland	43.1	Seychelles	34.2	Bangladesh	27.6	Sierra Leone	19.4
Bosnia & Herzegovina.	43.1	Antigua & Barbuda	34.0	El Salvador	27.6	Togo	19.4
Switzerland	43.1	Sri Lanka	34.0	Turkmenistan	26.9	Eritrea	19.2
Malta	42.6	New Caledonia	33.6	Guyana	26.7	Congo	19.2
US Virgin Islands	42.6	French Polynesia	33.6	Djibouti	26.6	South Sudan	19.0

Channel Isl.	42.6	Brazil	33.5	Nicaragua	26.5	Côte d'Ivoire	18.9
Taiwan	42.5	Costa Rica	33.5	Paraguay	26.3	Guinea-Bissau	18.8
Estonia	42.4	Saint Vincent & Gren.	32.9	Kyrgyzstan	26.0	Benin	18.8
France	42.3	Tunisia	32.8	Philippines	25.7	Cameroon	18.7
Denmark	42.3	UAE	32.6	Cambodia	25.6	Zimbabwe	18.7
Singapore	42.2	Viet Nam	32.5	Syria	25.6	Sao Tome & Princ.	18.6
Cuba	42.2	Bahrain	32.5	Bolivia	25.6	Senegal	18.5
Belgium	41.9	Azerbaijan	32.3	Belize	25.5	Afghanistan	18.4
Poland	41.7	Brunei Darussalem	32.3	French Guiana	25.1	Malawi	18.1
Serbia	41.6	Qatar	32.3	Nepal	24.6	Nigeria	18.1
Curaçao	41.6	Bahamas	32.3	Egypt	24.6	Guinea	18.0
Slovakia	41.2	Grenada	32.0	Lao P.D.R.	24.4	Tanzania	18.0
Ukraine	41.2	Iran	32.0	Micronesia (Fed.)	24.4	Gambia	17.8
Canada	41.1	Saudi Arabia	31.8	Honduras	24.3	Mozambique	17.6
Sweden	41.1	Turkey	31.5	Botswana	24.0	C.A.R.	17.6
Aruba	41.0	Argentina	31.5	Lesotho	24.0	Zambia	17.6
Barbados	40.5	Guam	31.4	Haiti	24.0	Burkina Faso	17.6
UK	40.5	Colombia	31.3	Jordan	23.8	Burundi	17.3
Belarus	40.3	Peru	31.0	Kiribati	23.0	Dem. Rep. Congo	17.0
Thailand	40.1	Jamaica	30.7	Guatemala	22.9	Uganda	16.7
Norway	39.8	Kazakhstan	30.7	Pakistan	22.8	Somalia	16.7
Luxembourg	39.7	Oman	30.6	Gabon	22.5	Angola	16.7
Russian Federation	39.6	Israel	30.5	Papua N.G.	22.4	Chad	16.6
China, Macao SAR	39.3	Malaysia	30.3	Tajikistan	22.4	Mali	16.3
						Niger	15.2

Source: Own representation of data from United Nations, Population Division, World Population Projections 2019

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