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The Sputnik V moment: biotech, biowarfare and COVID-19 vaccine development in Russia and in former Soviet satellite states

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ABSTRACT

Why have Russia and Cuba developed and produced vaccines against COVID-19 while Central and Eastern European (CEE) countries that are members of the European Union have only played a marginal role in the global supply of such vaccines? We argue that the answer is to be found in the capacity of Russia's national security state and entrepreneurs to mobilise historic Soviet advantages as part of a broader security motivated statecraft. CEE countries lacked this legacy and this drive. Similarly, they failed to massively invest – as for example, Cuba has – into potential synergies between public health systems and biotech firms.

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In his classic *Dependent Development*, Peter Evans (1979) showed that when it comes to innovation in general and pharmaceutical innovation in particular, multinational firms tend to keep the cards close to their chest. Indeed, he argued, the only hope for serious domestic innovation breakthroughs comes from partnerships between states and local capital. This seems to have been the case with the innovation of anti-COVID-19 vaccines. In the winter of 2020/21, Janssen (Johnson & Johnson), Moderna, Oxford-AstraZeneca, Pfizer-BioNTech or Sputnik V all became household names as millions of doses of COVID-19 vaccines started being administered to the public. Except for Sputnik V, none of these names had a Slavic resonance to them. Nor did they have Baltic, Finno-Ugric or Romance roots. In fact, none of the European Union (EU) member states from Central and Eastern Europe (CEE) played any role in the development of the abovementioned vaccines. Among former Soviet satellite states, only Cuba also defied conventional wisdom by developing the Soberana 2 vaccine in early 2021.

By the end of 2021, the only EU-based CEE site that was clearly set to become a manufacturing facility for a COVID-19 vaccine was a Czech enterprise – Praha Vaccines – that the American biotech firm Novavax had acquired from an Indian firm in May 2020 (Novavax 2020). Novavax and Polish biotech firm Mabion had also entered a framework

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agreement that would lead to Mabion producing antigen for the American firm's COVID-19 vaccine (Mabion 2021). Meanwhile, governments, pharmaceutical firms and research institutes in almost all other EU member states from the CEE region expressed a *desire* to participate in the production of COVID-19 vaccines although it was far from evident that they would be quickly able to overcome all the technological and regulatory obstacles on the way to high-tech vaccine production (capital.bg 2021; err.ee 2021; hnon-line.sk 2021; koronavirus.gov.hu 2021; lrv.lt 2021; lsm.lv 2021; romaniajournal.ro 2021; tportal.hr 2021). Against this background of a peripheral involvement of most CEE countries in COVID-19 vaccine production, Russia's relative success in developing *and* producing Sputnik V (Gam-COVID-Vac) – and, incidentally, in helping Serbia's Institute of Virology, Vaccines and Sera “Torlak” to produce it (RDIF 2021a) – stands out.

To be sure, this vaccine's efficacy was initially met with great scepticism among experts and the public because of Russian authorities' decision to grant it emergency approval before large-scale Phase III randomised controlled trials were even carried out. But, once the results of those trials were reported in the *Lancet* (Logunov et al. 2021), the vaccine started gaining some legitimacy within the scientific community (Jones and Roy 2021; van Tulleken 2021; but see Sheldrick, Meyerowitz-Katz, and Tucker-Kellogg 2022) even if it continued arousing contention in the political sphere, particularly within CEE (Guasti and Bílek 2022).

The stark contrast between Russia's capacity and CEE EU member states' incapacity to jump on the COVID-19 vaccine development bandwagon is puzzling for students of comparative capitalisms. Political economists have for a long time pointed to the limits of CEE EU member states' growth models based on the attraction of foreign direct investment and on the (limited) transfer of innovations within the foreign-owned transnational corporations that dominate their economies (Nölke and Vliegenthart 2009; Bohle and Greskovits 2012; Ban, Scheiring, and Vasile 2021). At the same time, it is these countries that have been typically perceived as the success stories of post-communist economic transformation (Åslund 2013) and that, for some of them, have been shown to have developed sufficient industrial policy capacity to help domestically owned firms move up the value chain (Bruszt and Karas 2020; Bruszt, Lundstedt, and Munkácsi 2020; Medve-Bálint and Šćepanović 2020). Most importantly, perhaps, all CEE countries – except for Bulgaria – out-ranked Russia both in terms of GDP per capita and innovation capacity at the outset of the COVID-19 pandemic (Appendix A.1). Given this, how come that it was not CEE but Russia that sat at the table of Covid vaccine innovators?

The literature on Russia magnifies the puzzle. Students of Russian capitalism have often focused on the predatory and corrupt practices of its business and state elites (Gans-Morse 2012; Ledeneva 2013; Yakovlev, Sobolev, and Kazun 2014; Åslund 2019). Although some have shown that Russia's rulers have been seeking to increase the country's economic competitiveness and have been borrowing from East Asian developmentalism in trying to do so (Gel'man 2016; Bluhm and Varga 2020), pockets of institutional excellence and of economic efficiency have remained rare (Freinkman and Yakovlev 2015), leading some commentators to even label Russia as a “failed developmental state” (Szakony 2020).

In order to address this puzzle, one has to start from examining states' capabilities in the biotech industry. Regardless of the overall state of Russia's political economy and of the scientific and political controversies – including accusations¹ of technology theft – that Sputnik V has sparked, there is good reason to believe that the state research

institutes that have developed this vaccine have constituted a pocket of scientific excellence whereas the privately owned biotechnological firms involved in its production made steps towards becoming internationally more competitive. Why have the state institutions and business sector of contemporary Russia been relatively successful in this specific endeavour? And why have their CEE counterparts played such a secondary role in vaccine production while not even seriously trying to develop home-grown vaccines against COVID-19?

Key to explaining this variation is the distinction between economically motivated statecraft and security motivated statecraft in a market economy (Weiss and Thurbon 2021). Modern vaccine development and production have become increasingly reliant on advances in biotechnology (Josefsberg and Buckland 2012). Driven by economic motivations over the biotech industry's capacity to generate high value added, many governments around the world – including Russia and some CEE countries – have tried to build institutional ecosystems that would help support this industry's growth in general, if not vaccine development and production in particular. Yet we argue that the deeper roots of Russia's capacity to develop and produce Sputnik V lie in its – more precisely, in the Soviet Union's – past as a “national security state” (NSS – on that concept, see Weiss 2014) that strove to achieve military and technological supremacy over the United States by pursuing, among other means, an enhanced – effectively, the world's most advanced – biological weapons programme from the mid-1970s until the early 1990s (Leitenberg, Zilinskas, and Kuhn 2012). It would not be entirely off the mark to see in this a positive form of conversion of the capabilities associated with a dangerous military programme into a public good par excellence.

The development of bioweapons effectively relies on biotechnology, and the existence of bioweapons leads armies and their biodefence institutions to – directly or indirectly – develop advanced vaccines against pathogens potentially used in such weapons. Armies also engage in biodefence in order to defend their troops against naturally occurring pathogens. Security experts can argue over these programmes yet what matters from the innovation and manufacturing perspective we are interested in here is that it is reasonable to expect that the more a country has been historically engaged in developing bioweapons, the stronger the science base of its biodefence institutions should be.

We do certainly *not* claim that Russia's capacity to develop and produce the Sputnik V vaccine directly stems from the Soviet bioweapons (BW) programme or that countries that do not have such military programmes cannot develop such vaccines. Indeed, our case study of Cuba shows that this is not a necessary condition everywhere. Yet we suggest that the state research institutes that have developed Sputnik V and the facilities upon which the largest Russian producers of the vaccine were built were all most likely involved in that programme or, at the very least, in Soviet biodefence. All of these institutions and firms have directly relied on the science base of Soviet biowarfare very much in the same way that the innovations undergirding the fourth industrial revolution in the US relied on the science base of Cold War era American investment in weapons programmes (Mazzucato 2015). Like in other parts of the post-Soviet defence industry, that science base has been maintained and subsequently renewed through a combination of security motivated statecraft targeting some of the same Soviet state research institutions now involved in Russian biodefence and of economically motivated statecraft supporting emerging Russian biotech firms. As the case of Cuba shows, one can develop

Covid vaccines without having such programmes. But the same case shows that one needs just as much scientific firepower to do so, something that a non-capitalist country such as Cuba, with its prided health system depending on a sophisticated pharma industry subject to a securitised external embargo, also had.

The contrast with CEE could not be greater. Despite their use of economically motivated statecraft to support their own emerging biotech industries, CEE EU member states have all lacked, firstly, this crucial ingredient of security motivated statecraft for biowarfare as they were either not – or very peripherally – involved in the Soviet bioweapons programme or they dismantled the capacities they inherited from it, and they are now all peripherally involved in NATO's biodefence. This perpetuated peripherality meant that there were too few scientific capabilities to draw upon to pull off the task of developing a vaccine for a pandemic as complex as COVID-19.

Secondly, as communism collapsed, CEE countries have underinvested in their health-care and public health systems and have failed to develop synergies between such systems and pharmaceutical firms or research institutes as, for example, the United Kingdom has – as evidenced by its Oxford-Astrazeneca (Gilbert and Green 2021) –, or, as we suggest, Cuba has. Cuba, a country that largely maintained its socialist economy stood out in this regard because it decided to “go big” on biotechnology by creating a vast network of institutes endowed with thousands of labs and privileged scientists whose work and products received accolades from fellow scientists in top scientific journals such as *Nature* at a time when CEE countries scientific infrastructure essentially degraded (Evenson 2007; Thorsteinsdóttir and Sáenz 2012; Thorsteinsdóttir et al. 2004). Given these scientific capabilities, it should not be very puzzling that Cuba developed its own vaccine and CEE did not despite this Caribbean country being a much less “developed” country by most economic metrics.

In the next section, we situate our argument by reviewing existing literature on the political economy of biotechnology and biowarfare. We then provide evidence for the argument through a case study of the origins of Sputnik V, and we contrast the Russian case with a discussion of five shadow cases, namely Czechia, Poland, Hungary, Romania and Cuba. It should be noted that “it has been made a crime for anyone in present-day Russia to divulge information about the former offensive BW program” (Leitenberg, Zilinskas, and Kuhn 2012, p. xii). Our Russian case study therefore only relies on – surprisingly rich – publicly available information on that programme. This means that we cannot really open the “black box of causality” and that the empirical strategy we use is closer to the congruence method than it is to process tracing (George and Bennett 2005). The last section concludes.

Developmental states and national security states

While political scientists have recently started exploring the politics of vaccination policies (Ansell and Lindvall 2020, Chapter 8), they have largely ignored the political economy of vaccine development and production. By contrast, there is a rich literature on the rise of the biotechnology industry, which now plays a crucial role in developing vaccines. States and their developmental institutions have been actively involved in promoting this sector whose product – particularly drug and vaccine – development process is characterised by inherent uncertainty (Wong 2011).

Governments have created various types of developmental arrangements that have effectively tried to address the “three challenges” characterising biotechnology: “first, accessing a science base that generates new knowledge and intellectual property; second, obtaining early funding for the timely development of a viable product; and third, navigating commercial and regulatory demands in taking the product to market” (Gilding et al. 2020). One typical policy instrument that partly addresses all three challenges is the creation of incubators and technology/science parks around universities or other types of research institutions. Such parks not only facilitate the diffusion of scientific knowledge and the creation of university spin-offs, but they also typically establish an administrative infrastructure that offers support to entrepreneurial researchers in, for example, finding seed funding for the commercialisation of their research findings or in designing business plans and accessing management consultancy services to help them take their product to market (e.g. Zhang, Cooke, and Wu 2011). Another widely used strategy to address the second challenge identified above has been to get states involved in venture capital either through direct state provision of venture capital funds or, increasingly, through the creation (state-owned) funds of (privately owned) venture capital funds (Klingler-Vidra 2018).

In particular, state support for biotechnology has also been shown to have been a key success factor in the rise of the world’s most salient biotech industry, namely US biotech (Block 2008, 176–178; Mazzucato 2015, chapter 3). Although Block’s and Mazzucato’s analyses would suggest that US developmentalism in this area has been driven by public health concerns, Linda Weiss (2014) – who characterises the US as a “national security state” pursuing perpetual innovation for military preparedness – has suggested that a more important driver has been security considerations.

Weiss argues that “health is a quintessentially dual-use agency, with one foot in the civilian sector and the other firmly planted in the NSS” (Weiss, 2014, 25). She indicates that, after the Second World War, the National Institutes of Health (NIH) partly inherited the charge of defending the health of US service personnel and of defence against biological and chemical weapons. Furthermore, Weiss argues that, following President Nixon’s decision to phase out the US’s bioweapons programme and the ratification of the Biological Weapons Convention (BWC) of 1972, “the federal government deployed the conversion process to kick-start a commercial dual-use biotechnology industry, transferring to the private sector a good deal of the technology that had been locked up in government labs” (Weiss 2014, 35). Weiss mentions the example of the conversion in 1972 of some of the Army’s former biological warfare facilities into a laboratory of the NIH-run National Cancer Institute (Weiss 2014).

There are further examples of such connections between the military and the US biotechnological industry. The state of Maryland has a strong biotechnology cluster, with many of its firms providing services to military research institutions (Feldman and Francis 2003). Military laboratories have also been a major source of entrepreneurs in the Maryland cluster (Feldman 2001). Also, after the 2001 “anthrax letters” attack, the US government created new programs coordinated by the newly created Biomedical Advanced Research and Development Authority (BARDA) (Lentzos 2006; Weiss 2014, 49) and spending on biodefence research increased 20-fold over the five years following the attacks (Reppy 2008, 802). Remarkably, the Department of Health and Human Services, the NIH, BARDA, the Department of Defense have all been mobilised to support the development of COVID-19 vaccines (Slaoui and Hepburn 2020).

The US emerged as an NSS during the post-war period because of its rivalry with the Soviet Union. “The Cold War was not simply an arms race but a science and technology race, as both the United States and the Soviet Union concentrated their resources to gain a technological edge over and impose technological surprise on each other” (Weiss 2014, 37). Although Weiss does not explicitly label the Soviet Union itself as an NSS, we believe that it is fair to do so.

To be sure, the USSR’s command economy proved to be much less efficient than American capitalism, but – as emphasised by Weiss herself – much of it was organised around a perceived need to ensure military and technological supremacy over the US. So was Soviet science, (Graham 1975, 324), which was organised around a system of research institutes attached to the Soviet Academy of Sciences or to specific ministries with a focus on “big technology” relevant to the military (Graham 1992). More than two thirds of overall R&D expenditure “went into military research; the defence industry was the major client of many, if not most, academy institutes” (Mayntz 1998, 788). Perhaps the last technological surprise this system caused was when, from the late 1980s, the West found out that the USSR had secretly upgraded its biological warfare programme throughout the 1970s and the 1980s despite it ratifying the 1972 BWC.

The substantive focus and organisational structure of the Soviet biowarfare programme have been documented in much detail (Alibek 1999; Domaradskii 2003; Leitenberg, Zilinskas, and Kuhn 2012; Rimmington 2003; 2019; 2021). An essential characteristic of the programme was that it relied both on a military component and on a civilian one. Both components were coordinated by the Ministry of Defence (MOD) while MOD facilities in Kirov, Sverdlovsk (now Yekaterinburg) and Zagorsk (now Sergiyev Posad) constituted the core of the programme. Remarkably, a civilian *Ferment* programme involved a very extensive network of research institutes, production plants and storage facilities controlled by the All-Union Science Production Association “Biopreparat”. Institutes from the USSR Academies of Sciences and Medical Sciences as well as the Ministry of Health were also involved in that programme (Leitenberg, Zilinskas, and Kuhn 2012, 8; 72). In addition, the Ministry of Health coordinated a so-called “Program 5” biodefence programme (Leitenberg, Zilinskas, and Kuhn 2012, Chapter 5). Finally, the Ministry of Agriculture ran an *Ekologiya* programme “to produce biological weapons directed against animals and plants” (Leitenberg, Zilinskas, and Kuhn 2012, 9).

The whole Soviet BW programme is estimated to have involved between 40,000 and 65,000 “scientists, engineers, technicians, and infrastructure support personnel” (Leitenberg, Zilinskas, and Kuhn 2012, 700) and is believed to have given the USSR a “research and development advantage ... on any foreign opponents” (Lilja, Roffey, and Westerdahl 1999 cited in Rimmington 2003, 5). The programme was officially phased out from 1992 following trilateral negotiations between the United Kingdom, the US and Russia with Western countries providing financial assistance – primarily through the Moscow-based International Science and Technology Centre (ISTC) – to help former civilian BW facilities convert to peacefully directed pursuits and to prevent scientists employed in them from emigrating and, potentially, helping terrorist groups or rogue state to develop their own BW programmes (Leitenberg, Zilinskas, and Kuhn 2012, chapters 22 and 23). Yet Russian authorities’ refusal to allow foreign visitors in former military BW facilities has led some

countries – particularly the US – to suspect that those facilities might still be pursuing offensive-directed activities² (Rimmington 2003).

Economic geographers have shown that regional patterns of innovation in contemporary Russia are still influenced by Soviet policies since endowment with Soviet-founded “science cities” remains a strong predictor of current patenting (Crescenzi and Jaax 2017). We argue that, in the case of COVID-19 vaccines, East European countries’ capacity to develop and produce such vaccines is influenced by the nature of their involvement in past (Cold War) BW programmes and in contemporary biodefence programmes. With their focus on the genetic engineering of dangerous viruses or bacteria, biowarfare programmes led to the accumulation of a highly specific science base that cannot be easily reproduced. Russia not only inherited such a science base from the Soviet Union, but, with its renewed ambition to exert a leading role on the global stage, it has sought to rebuild some of its capacities as a “national security state”, including in biowarfare/biodefence. By contrast, former Soviet satellite states were either not involved or only peripherally involved in the Soviet BW programme (Leitenberg, Zilinskas, and Kuhn 2012, chapter 17) and they are now peripherally involved in NATO’s biodefence.

In a market economy, reliance on the traditional tools of “economically motivated statecraft” is insufficient because it leads to the creation of biotech firms that lack the commercial incentives to develop the science base needed for the rapid development of vaccines against rare viruses. As has been put by a team of virologists from military and civilian laboratories located in Fort Detrick (Maryland), “development of vaccines for protection against infection with rare or exotic pathogens typically falls into the spheres of public health and/or biodefence. Such development does not, however, often pique the interest from the pharmaceutical industry. With little financial incentive to justify a private company’s investment into vaccines that only few people would actually need, candidate vaccines for rare diseases often languish at the research bench stage, regardless of the strength of the preclinical studies assessing them” (Martins et al. 2016, 1101).

We now move on to the empirical evidence.

Developing Sputnik V

After Russian authorities controversially authorised Sputnik V in the summer of 2020 before Phase III trials, Kirill Dmitriev, the head of the Russian Direct Investment Fund – the sovereign wealth fund that has helped coordinate the production and marketing of Sputnik V –, defended its credibility by pointing out, among others, that “the US military gives all of its conscripts human adenovirus vaccines since 1971. So, it is very different from the mRNA and the monkey adenovirus approaches that are new” (Bloomberg 2020, 0:20-0:40).

Adenovirus *vectors* had started being massively researched from the 1980s because they offered a promising system for gene therapy and vaccine development (e.g. Graham and Prevec 1992). Their potential as platform technologies for vaccines against biowarfare or bioterror pathogens such as anthrax, plague and Ebola had also been recognised for a long time (Boyer et al. 2005). Yet, by early 2020, the only adenovirus-based vaccine to have ever been granted marketing authorisation in the OECD was the Zabdeno-Mvabea Ebola vaccine whose adenovirus-based Zabdeno (Ad26.ZEBOV) component had been developed by Janssen Pharmaceutical Companies of Johnson & Johnson (J&J 2020).

The mass media has focused on the role played by the Gamaleya National Center of Epidemiology and Microbiology of the Russian Ministry of Health (MOH) in developing the vaccine, but one of the leaders of the “Sputnik V Team” and a co-author of the team’s publications in *The Lancet* is Sergei Borisevich, the head of the 48th Central Scientific Institute of the Russian Ministry of Defence (MOD; Appendix A.2; Logunov et al. 2020; Logunov et al. 2021). Researchers at that Institute conducted pre-clinical trials and clinical (Phases I and II) trials on several dozens of volunteers (Logunov et al. 2020, 889; TASS 2020). In *Krasnaya Zvezda* (Red Star) – the official newspaper of the Russian Armed Forces, Borisevich said:

It would be impossible to even start designing a vaccine without studying the biological properties of the pathogen COVID-19 and without characterising the vaccine strain. But the 48th Central Research Institute has already worked out the methodology for the quantitative assessment of the pathogen and has developed a laboratory model that allows reproducing the course of SARS-CoV in order to assess the protective efficacy of drugs. Patents for these inventions belong to the Institute. (...) In this regard, the experience of 2003 – when our employees were actively involved in the fight against SARS – helped us significantly reduce research time. I note that it was in the 48th Central Research Institute that, for the first time in Russia, the causative agent of SARS was isolated. (Alekseev 2020)

Based in the city of Kirov since 1941, the 48th Institute used to be known as the Red Army’s Scientific-Research Institute of Epidemiology and Hygiene and is notorious for having been the “hub” of the Soviet biological weapons (BW) programme (Rimington 2019, 176; Leitenberg, Zilinskas, and Kuhn 2012). A 1992 Trilateral Agreement between Russia, the US and the United Kingdom prescribed that the three signatories would be able to visit their BW-related facilities, but Russian authorities have ever since refused to give foreigners access to the Kirov Institute and closely related facilities in Yekaterinburg and Sergiyev Posad. In another interview in *Krasnaya Zvezda*, the Gamaleya Institute’s director, Alexander Gintsburg, explained that:

Together with the Ministry of Defence of the Russian Federation, primarily with the 48th Central Research Institute, we managed to pass virtually all research and preclinical tests in record time. This became possible because, before that, we had developed several vaccines and drugs that were registered in the Russian Federation. (...) Scientific cooperation of our institute with medical organisations of the Russian Federation’s Ministry of Defence began a long time ago – not only when I became the director of the Gamaleya Institute, which, by the way, was 24 years ago. I inherited this cooperation. (...) I am very grateful to the Defence Department ... for their very fruitful and high-quality work. (Biryulin 2020)

The Gamaleya Institute is a public health institution, but, in the Soviet Union, it was also the hub of the so-called “Problem 5” biodefence programme (Leitenberg, Zilinskas, and Kuhn 2012, Chapter 5). The programme “had entire closed institutes dedicated to it, as well as laboratories within the Biopreparat institutes and otherwise open institutes” (Leitenberg, Zilinskas, and Kuhn 2012, 146). Problem 5 is believed to have also contributed to the Soviet offensive BW programme, for example by handling and supplying virulent pathogens to *Biopreparat* and MOD biological facilities “that were subsequently developed for military purposes” (Leitenberg, Zilinskas, and Kuhn 2012, 151). The programme was run by a commission that was headquartered at Gamaleya thereby making the Institute a direct consumer and producer of state-of-the-art research in biowarfare-related genetic engineering.

Gamaleya researchers have emphasised the importance of the USSR's science base to explain the exceptionally rapid development of Sputnik V. On the state-owned television's news service *Vesti*, Gamaleya's deputy director, Denis Logunov stressed that "nothing could have been done without people and without the school that was founded in the Soviet Union" (Erofeyeva 2021) and that "the founding father of all this [adenovirus vector] technology in Russia is Boris S. Naroditsky. This is my teacher. He began his work in the late 70s of the last century" (Erofeyeva 2021). Naroditsky himself stressed: "This is the strength of the Gamaleya Institute. Here, the continuity of generations is preserved. This is something that was very lost in the 90s in many institutions. (...) This is an essential component" (Erofeyeva 2021). Alexander Gintsburg also emphasised that "one of [his] main achievements as director ... is that four generations of employees are now working at the Gamaleya Institute, and they are actively working – 90-year-old employees – Zuev, Kostyukov, Ershov, Lvov – and 25-year-olds. The platform began to be created 20, or even 25 years ago" (Vesti 2021).

Of course, the science base of institutions involved in biodefence research had to be cultivated and renewed in recent decades. One important state initiative was the 1999 "Protection against pathogens" federal target programme (Russian Government 1999; see also Leitenberg, Zilinskas, and Kuhn 2012, 661 and 673). Among other things, it allocated funds to the "technical re-equipment of the experimental production" of the Gamaleya Institute and to the "reconstruction and technical re-equipment" of military facilities in Kirov, Yekaterinburg and Sergiev Posad (Russian Government 1999). At Gamaleya itself (and, effectively, at the MOD's 48th Central Scientific Institute), research on adenovirus vectors was really relaunched in the 2010s with the outbreak of epidemics of Ebola and MERS.³ Alexander Gintsburg said that "when it was necessary to create a new technology against those pathogens against which there were no vaccine preparations 10 years ago, we evaluated this technology, and Denis Y. Logunov and his employees began to actively use this technology to create ... a vaccine against the pathogen Ebola and against another coronavirus, the MERS coronavirus" (Vesti 2021).

Producing Sputnik V

Not only were the Gamaleya Institute and the 48th Central Scientific Institute able to develop Sputnik V in record time, but Gamaleya and six Russian firms – Binnopharm, Biocad, Generium, Lekko, R-Pharm and Pharmstandard – have been involved in its production (Rogoża and Wiśniewska 2021). To be sure, these firms struggled to deliver on their promise to supply hundreds of millions of vaccines to the domestic and foreign markets (Nikolskaya and Ivanova 2021). They had not produced high-tech viral vector vaccines on a massive scale before the COVID-19 pandemic and had to repurpose their existing facilities to that end once Sputnik V had been developed. They also lacked the raw materials required for the vaccine's production (Kotova 2021). Agreements negotiated by RDIF with Indian and Chinese companies to mass-produce Sputnik V abroad were essential for Russia's capacity to honour its commitments towards foreign governments (RDIF 2021b; Wu and Litvinova 2021).

Yet, in comparison with the almost total lack of involvement of EU-based CEE biotechnological firms in the production of COVID-19 vaccines, the capacity of Russia's hitherto largely unknown biotech firms to produce adenoviral vector-based vaccines is still

remarkable. How did these firms acquire this technological capacity? The explanation lies in Russian biotech entrepreneurs' readiness to tap both into state support provided as part of Russia's more recent "economically motivated statecraft" and into the science base of the USSR's bioweapons programme.

Among the six firms producing Sputnik V, Generium is the "biggest producer" while Biocad is considered as "the only other major producer" (Nikolskaya and Ivanova 2021). Together with Lekko and Pharmstandard, these two firms are controlled by "oligarch" Viktor Kharitonin. Generium and Biocad both benefited from state support as part of "Pharma 2020", an import-substitution programme launched in 2009 by the Ministry of Trade and Industry (MTI) under the aegis of President Dmitry Medvedev (Zvonareva 2020, chapter 4). Its aim was to reduce Russia's dependence on foreign-developed pharmaceutical products from 80% of all drugs sold in Russia to 50% by 2020. Biocad's Morozov described himself as "one of [its] authors" (Biocad.ru 2015). Generium and Biocad were at the centre of two "priority" projects out of Pharma 2020's five such projects (Finmarket 2009). The Generium project was to result in the creation of a high-tech research centre in biotechnology. Biocad was to develop "a full cycle of production of drugs based on monoclonal antibodies ... [which] are highly effective in the treatment of the most common cancers" (Finmarket 2009). Both companies were to benefit from sped-up registration procedures for drugs.

Generium's original infrastructure was financed by Lekko and Pharmstandard, but it was built on land allocated by the Vladimir Region (Ria Novosti 2011). The firm further developed its facilities thanks to a preferential loan from the MTI-controlled Industrial Development Fund (IDF 2018). Originally based in the outskirts of Moscow, Biocad moved its headquarters to St Petersburg in the early 2010s. In doing so, it saw Russia's development bank Vnesheconombank finance a large part of its new complex in the St. Petersburg special economic zone that has set the establishment of a cluster in medical technologies and pharmaceuticals as one of its priority areas (pharmvestnik.ru, 2012). Like Generium, Biocad benefited from a preferential loan from the Industrial Development Fund to expand that new site (IDF 2016). In addition, Biocad became a resident of the Zelenograd-based (Moscow) "Technopolis" special economic zone that also has medtech and life science as a priority area (Kotova 2017).

While directly benefiting from the Russian Federation's new developmentalism in the 2010s, both Generium and Biocad have their beginnings in specific entrepreneurs' decision to use former *Biopreparat* closed facilities and their staff as the foundation for establishing their firms and their R&D centres.

Generium is located in the Vladimir Region's Volginsky "settlement" (*posyolok*) which was the site of "an organised BW programme of the Ministry of Agriculture, codenamed "Ekologiya"" (Kuhn and Leitenberg 2016, 95) and where Lekko is also located. Generium was a Lekko-initiated project to establish a 60 million euro "Genetic Engineering Center" for the development and production of new generation medicines (Novecon 2007) before Kharitonin's Pharmstandard supported it through a joint venture.

Lekko's official company website reports that the company "began its activity in 1993 on the basis of one of the production buildings of the Pokrovsky plant of biological preparations with the production of probiotics". The Pokrov plant – which belonged to the Ministry of Agriculture – is also a former BW facility (Leitenberg, Zilinskas, and Kuhn 2012, Table 6.1, p. 161).

At the time the Generium centre was built, the company's deputy director-general, Vitaly Pantyushenko, argued that "there was a very intelligent environment in Volginsky from the beginning", but the company saw itself as contributing to the village's "renaissance" because "today, the research and production "cluster" in Volginsky, which includes several enterprises at once, mainly related to pharmaceuticals, has almost completely used the human potential that is available in the village" (Generium.ru 2011).

The history of the Biocad company and of the R&D centre that allowed it to develop new products has been much better documented. Having worked as a banker in the 1990s, Dmitry Morozov decided in 1999 to set up a start-up that would be the first one to develop and produce genetically engineered pharmaceutical products in Russia (Naumov, Petrovskaya, and Puffer 2008). On his own admission, Morozov bought the centre because he was intent on tapping into the science base of the Soviet Union's bio-warfare programme (Naumov, Petrovskaya, and Puffer 2008, 15).

Morozov first set up a distribution company that manufactured biotech generics, but, as he learnt in 2000 from a Biopreparat manager that one of its research institutes was going bankrupt, Morozov bought a very large part of it – including laboratories, equipment and scientific staff – and transformed it into his company's R&D centre (Naumov, Petrovskaya, and Puffer 2008, pp. 14-17) by using, among other sources, funding from the US State Department for supporting civilian research by former BW weapons facilities (Naumov, Petrovskaya, and Puffer 2008, 17). The Biopreparat institute in question was the "Institute of Engineering Immunology" (IEI) that was created in 1979 (Leitenberg, Zilinskas, and Kuhn 2012, 261–274) and whose main objectives were "to assess the immune response of animals to pathogens of BW interest, to discover immune system weaknesses that could be exploited by new BW agents, to overcome immune responses induced by current vaccines, and to develop vaccines to protect Biopreparat scientific workers from the pathogens on which they worked" (Leitenberg, Zilinskas, and Kuhn 2012, 261–274). The IEI's staff and science base had been able to survive until Morozov's take-over mainly because, in 1995–2001, 87 percent of the Institute's funding came from the US-funded International Science and Technology Centre that supported the redeployment of BW facilities towards civilian research (Rimington 2021, 159–160).

In an official history of Biocad, Valentina Mogutnova, a lead manager-consultant who had worked at the IEI in the 1980s, said that "the structure was closed and worked for defence" (Stogov 2018, 24) and added that "we did not create weapons. On the contrary, the challenge was to develop remedies" (Stogov 2018, 25). No matter the type of activity in which the Volginsky-based facilities and the IEI had to engage in the USSR's "national security state", there is little doubt that it is because they directly built on the science developed in those facilities that Generium and Biocad became potential "national champions" worthy of being supported by Russian's developmental institutions in the 2010s and eventually becoming capable of producing COVID-19 vaccines on an emergency basis.

COVID-19 vaccines in former satellite states: Czechia, Poland, Hungary, Romania

Unlike in Russia, the security systems of East-Central Europe had neither the finances and research capabilities nor the "national security state" drive that Moscow had. Additionally, their dependent research and development systems weighed down heavily on their

capacity to not only develop vaccines, but also to manufacture vaccines developed abroad. As the analysis below shows, Czechia's and Poland's modest insertion in global vaccine production chains had to do with a combination of state support and international investment. The lack of both in Romania led to failure and a strong assertion of the dynamics of dependence. Hungary lies in between these two CEE extremes, with some recent build-up in vaccine production and innovation efforts. But, everywhere, the amounts of biotech scientific capabilities and investment generated by Russia's security motivated statecraft dwarfed anything that CEE countries could mobilise with their more modest economically motivated statecraft and the typically peripheral biotech capabilities they derived from orbiting the Soviet BW programme.

It is striking that, as CEE's industrially most sophisticated economy, Czechia plays only a modest role as a manufacturer of foreign-developed vaccines. Following the Great War, the newly founded Czechoslovak state established a National Institute of Health to, among other things, develop and produce serums and vaccines. After World War II, a number of military facilities – particularly a laboratory of the Institute of Immunology and Microbiology of Jan Evangelista Purkyně Military Medical Academy in Těchonín in East Bohemia – became incorporated into the Soviet BW programme (Leitenberg, Zilinskas, and Kuhn 2012, 462–468). Yet, like elsewhere in the region, state funding declined immediately after 1990.

Two sources of rejuvenation emerged. The first was NATO membership, which upgraded Těchonín into CEE's only military BSL-4 laboratory, with evidence of military-civilian collaborations in COVID-19-related biomedical research provided by publications in prominent journals such as *Nature*.⁴ Yet there is no evidence of spillovers from such research into the Czech biotechnological industry. Secondly, international biotech capital helped integrate the Czech biotech sector into high-value-added activities. After 1989, a plasma processing plant was built in Bohumil on a former vaccine production site of the National Institute of Health. The plant was privatised with American company Baxter and it produced flu vaccines using the advanced serum-free Vero cell technology for its European vaccine division. In 2015, the Cyrus Poonawalla Group [which is the holding company that owns the Serum Institute of India, the world's largest producer of vaccines that has partnered, among others, with AstraZeneca and Novavax to manufacture COVID-19 vaccines in India] purchased the facility from Baxter. In May 2020, the Bohumil facility was acquired by Novavax for USD 167 million to provide capabilities to produce a vaccine against COVID-19.⁵

Like Czechia, Poland is an intermediary case. In terms of vaccine research capabilities historically linked to the military, Poland remains far apart from Russia. Its military epidemiological institution (WIHE) had a very peripheral involvement in the Soviet bioweapons programme (Leitenberg, Zilinskas, and Kuhn 2012, 472–473). Despite knowledge exchange with US military labs as part of NATO membership, WIHE operates no advanced BSL-4 lab that could do research on the most dangerous pathogens (Chomiczewski 2019). Moreover, it remained bedevilled by corruption and mismanagement accusations and, hence, resignations at the top in the middle of COVID-19.⁶ There was also no evidence of any collaboration between WIHE and Polish biotech companies.⁷

Overall, Polish pharma was too weak to develop homegrown vaccines against COVID-19. During socialism, Poland developed its domestic vaccine production base around the BIOMED conglomerate that was broken into three separate units after 1990. This

fragmentation meant that vaccine development and production was “crawling”.⁸ Yet, with Poland’s neo-developmental turn in the 2010s (Naczyk 2021a), growing state-capital coordination helped to insert emerging biotech “national champion” Mabion – a privately owned firm that was established as a joint venture by one of the BIOMED plants – into global supply chains of COVID-19 vaccines and to allow it diversify its activities through a deal with Novavax. As the Polish state’s 2017 “Strategy for Responsible Development” has identified biotech as a priority sector, Mabion had received equity funding since 2018 from PFR Life Science – a specialised unit of the state-owned Polish Development Fund (PFR). PFR and Mabion negotiated a deal with Novavax for the transfer of the U.S. company’s COVID-19 vaccination technology, with PFR providing \$11 million in loans and equity so the company can double its production capacity.⁹

Like Czechia, Romania had had a world-leading state-run serum institute – the Cantacuzino – that had been established in 1921 and had become, during the communist period, one of the 11 producers in the world authorised by the WHO to produce vaccines for seasonal influenza strains. The end of socialism led to massive defunding and ministerial decisions to favour polyfunctional vaccines led in 1992 to the closing of production lines for vaccines against polio, whooping cough and smallpox. Yet, unlike in Poland and Czechia, no spin-off structures splintering from the socialist research and production infrastructure morphed into biotech firms with real capabilities. Instead of seeing its most competitive parts salvaged, the Cantacuzino got gradually defunded and disabled in line with well-known expectations about Romania’s weak state (Bohle and Greskovits 2012). After years of mismanagement, the production of seasonal influenza vaccines – the institute’s most reliable source of income – was killed by a 2009 decision to import GlaxoSmith Kline vaccines against the background of a murky media campaign alleging that Cantacuzino’s decades-tested vaccine posed a risk of cancer. The accusations were never proven, but the pressure was sufficient to lead to the closing of all vaccine production lines by 2010. That year, the European Medicines Authority even withdrew the authorisation to produce vaccines that the Cantacuzino Institute had had for decades. A few years later, the institute did not have enough money to pay its employees, leading to mass resignations and an ensuing brain drain.¹⁰ In a desperate move, it was integrated into the Ministry of Defence in 2017, where it had shrunk to the status of a storage and vaccination site.¹¹ By 2021 its capabilities had been so depleted that its managers estimated that even with adequate financing it would take 3–5 years before it could manufacture COVID-19 vaccines developed elsewhere.¹²

Despite the existence of biotech and biotech-related departments in leading local universities, and with no less than 13 state institutes related to biotech,¹³ a domestically-owned private sector biotech alternative did not emerge from the rubble of the country’s once extensive pharma industry. This poor result is related to extremely low funding: The country spends almost 20 times less on R&D per capita than the European average and R&D in biotech is poorly connected with the business community (Dettenhofer et al. 2018). The Romanian state refrained from neo-developmental interventions in the sector. As a result, Terapia, the country’s largest drug maker did not go further than the manufacturing of medicine for the treatment of moderate forms of COVID-19 in hospitals (FluGuard).¹⁴ A cursory look at the top tech biotech firms in Romania shows that they are merely distributors for European and American pharma multinationals who are reluctant to develop local research centres and to frame

specific R&D activities (Dettenhofer et al. 2018). As for the capabilities of the military, it suffices to say that Romania was even more peripheral than Poland and the Czech Republic in the Soviet biological weapons programme and never maintained any capabilities of this kind after 1990.¹⁵

Hungary is an interesting shadow case because despite inheriting the former Eastern Bloc's most prominent pharma industry, including in biotech (Dibner and Steven Burrill 1988; Bross, Inzelt, and Reiß 1998; Vargha 2018), it did not yet have any COVID-19 production capacities at the time of writing. Yet, unlike Romania, Hungary had launched state-led efforts in both innovation and production. Indeed, while scholars have pointed out that the Fidesz governments have not taken the high road to industrial policy and that innovation capabilities may have in fact declined in the country (Bohle and Greskovits 2019; Ban, Scheiring, and Vasile 2021; see also Bohle et al. 2022), the government adopted a more neo-developmental attitude in vaccine production and innovation by bankrolling what it hoped it would be a state-owned industrial champion as well as a COVID-19 vaccine development programme.

Thus, in early 2021, the government announced the establishment of a vaccine factory in Debrecen (Hungary's second-largest city and the site of a budding academic-industrial complex) as a state-owned enterprise.¹⁶ Suggestively, the initiative belonged not to the health ministry but to the innovation and technology ministry and was cast both in public health terms and as a matter of economically motivated statecraft (international competitiveness in a neglected global niche).¹⁷ The Debrecen vaccine factory's construction site was due to be inaugurated in the summer of 2021 and to be completed in late 2022. Similarly, the government announced that Hungary had a domestic COVID-19 vaccine programme that used the basics of the technology used by China's Sinopharm.¹⁸ It is too soon, however, to assess how much of a difference such initiatives will make for Hungary's current marginal role in the race for the anti-Covid vaccines.

Cuba: socialist science and COVID-19

The case of Cuba, a country that faces serious shortages of basic medicines, is an interesting historical counterfactual for the conventional argument that rapid vaccine development requires investment that only relatively "advanced" countries can afford. Thus, in early 2021, Cuba's Finlay Institute and Centre for Genetic Engineering and Biotechnology developed a COVID-19 vaccine that met the basic WHO standards and was positively reviewed in *Nature*.¹⁹ To date, however, the Cuban vaccines have not received the approval of the WHO, nor have the results reported by Cuban scientists cleared peer review with top medical journals.

Still, Cuba's situation compared favourably with CEE and draws interesting parallels with Russia. This innovation took place despite that country presumably *not* inheriting an advanced biological warfare complex from the Cold War. Instead, Cuba developed a vaccine that Cuban scientists claimed had Pfizer-grade effectiveness.²⁰ The country did so by drawing on a civilian scientific base built during socialism as part of that country's known emphasis on delivering quality healthcare under conditions of a decades long embargo.²¹

Thus, biotechnology took off in the 1980s with the creation of the Biological Front (directly overseen by the highest level of government) and the launch of the Biological

Research Centre in 1981, the Genetic Engineering and Biotechnology Centre in 1986, the Immunoassay Centre in 1987, and the other institutions that by 1992 were included in the Western Havana Scientific Pole, with more than 10,000 employees. In 2012, these institutions merged with the enterprises of the pharmaceutical industry, and together gave rise to the umbrella company BioCubaFarma, which at this writing includes 34 enterprises, supplies the health system with more than 1000 products (including 62% of the essential medicines list), holds 182 patents, conducts over 100 simultaneous clinical trials with its products at 200 clinical sites, and exports to 49 countries. Top researchers at these institutes who led the effort of developing anti-COVID-19 vaccines such as Dr. Vérez Bencomo received the highest international awards and have been involved in research with leading scientific institutes in Canada and Europe.²²

With the advent of biotechnology in Cuba there arose the concept of the “research and production centre”, where scientific research, production and export activities take place under the same management in a closed financial loop, the precursor of the high-tech socialist state enterprise. These institutions embody a trend that emerged in the industrial sectors of the more technologically developed world in the mid-twentieth century, whereby scientific research became an integral part of the activities of corporations, which *ipso facto*, shouldered the burden of their financing.

One of BioCubaFarma’s eight institutes, Finlay Institute, acted as an integrated vaccine research and production centre since the early 1990s. This is not some “copycat vaccine factory”. In the 1980s, its researchers developed the first vaccine in the world against meningitis B, a drug that effectively halted an epidemic of this disease (Thorsteinsdóttir and Sáenz 2012). The state ensured that the scientists receive wages that are double and Cuba’s drug regulator is also considered a centre of reference by the WHO.²³

As a result of this decades-long scientific push in public health and institutional quality in the area of drug regulation, of the vaccines used in Cuba, 80 percent came out of Finlay’s labs. The Cuban example suggests that it is not the legacies of biodefence that matter everywhere and that there are less militarised ways that even small and poor countries can deploy to become cutting-edge innovators in something as conventionally capital-intensive as biotech.

In many ways, the Cuban case highlights the decay of medical innovation in CEE after socialism. But, perhaps, it also means that, in non-core economies that are not biodefence superpowers, doing biotech competitively enough to develop a fast-track COVID-19 vaccine may entail the very specific geopolitical status and ideological project that Cuba has. Geopolitically, Cuba is a target of a US-imposed blockade (intensified since the pandemic) and therefore had to make do with its domestic biotech to vaccinate 74 percent of its people by late 2021 (compared to 2.9 percent in countries at a similar level of income).²⁴ Ideologically, public health and medical supply autonomy has been for decades at the core of the country’s fusion of socialism and nationalism. While CEE countries had elements of this system as well until 1989, they abandoned in the 1990s and, with it, their vaccine developing and producing capabilities.

Conclusion

Students of the political economy of contemporary Eastern Europe stand to be puzzled by the contrast between Russia’s capacity and CEE EU member states’ incapacity to become

relevant in COVID-19 vaccine development. While CEE has been depicted as the success story of post-communist economic transformation and some parts of the region have been hailed for dramatic moves up the value chain, work on Russian capitalism dwelt on its pathologies and failures. In our view, it is largely unrecognised pockets of – relative – institutional excellence and economic efficiency that characterise parts of the Russian political economy and particularly parts of the Russian state that account for the Russian-CEE contrast. This paper shows that the state research institutes that have developed Sputnik V and the privately-owned biotechnological firms involved in its production represent an understudied case of potentially world-competitive entities.

The evidence suggests that the existence of security motivated statecraft in Russia and lack thereof – and, as the Cuban case suggests, public-health-driven statecraft – in CEE explains this variation. Russia's deep-rooted "national security state" geared around achieving military and technological supremacy over rivals (including via biological weapons) had built capabilities that turned out to have been more systematically saved from post-communist collapse than one would expect and were then deployed with some success after the COVID-19 pandemic struck. Rather than fit the conventional image of Russian billionaires as political insiders pillaging the Soviet legacy, domestic biotech investors in Russia appear to be more like conventional risk-taking entrepreneurs that capitalised on the Soviet legacy of expertise and by 2020 were in a position to provide additional support to the Russian vaccine push.

CEE's security systems and military research capabilities moved from a peripheral position in the Warsaw Pact to a peripheral position in NATO, and have always lacked the "national security state" drive that both Moscow and Washington have. Nor have CEE countries been able – or had the ambition – to bolster their healthcare systems and create – as Cuba has – synergies between a strong public health system and an emerging biotech sector. To be sure, economically motivated statecraft has allowed some Czech and Polish biotech firms to emerge, but, in the case of COVID-19 vaccine production, reliance on foreign investors was seen as a *sine qua non* – which is very much in line with those countries' FDI-led growth models. The lack of such statecraft and efforts to attract pharma FDI in Romania has prevented that country from challenging its own dependence on foreign-produced pharmaceutical products. Only Hungary has shown a more nationalist and developmentalist drive to set up its own state-owned COVID-19 vaccine production facility, but the success of this operation remained highly uncertain.

Notes

1. For example, there were reports that British intelligence had evidence of Russian spies stealing the blueprint for the Oxford/AstraZeneca vaccine (Patel and Robinson 2021). As social science researchers, we do obviously not have access to such intelligence. Beyond the Kremlin's dismissal of such claims (Patel, Jewers, and Robinson 2021), it should be noted that the Sputnik V vaccine uses a slightly different – *human*-adenovirus-vector-based – technology from Oxford/AstraZeneca's *chimpanzee*-adenovirus-vector-based vaccine. Furthermore, as we document in a more detailed version of the Russian case study, the institutions that developed Sputnik V had already conducted Phase III trials on a similar *human*-adenovirus-vector-based vaccine technology against Ebola in Guinea in 2017–2019 (Naczyk 2021b, 8).
2. It is also noteworthy that, for many years, Russia has been sowing disinformation by claiming that the United States itself has been using laboratories in Ukraine and in other former Soviet

- republics for producing its own bioweapons. Russia escalated this disinformation campaign after it invaded Ukraine in early 2022 (Lentzos and Littlewood 2022).
3. For a more detailed discussion of this period, see Naczyk (2021b).
 4. <https://www.nature.com/articles/s41586-021-03461-y>
 5. <https://www.pharmaceutical-technology.com/projects/novavax-covid-19-vaccine-manufacturing-facility/>
 6. <https://wiadomosci.onet.pl/tylko-w-onecie/rozklad-wojskowego-instytutu-do-walki-z-koronawirusem/14n9yyt>
 7. Author correspondence with former official at the Ministry of Development.
 8. Ibid.
 9. https://www.reuters.com/article/us-health-coronavirus-poland-mabion-idUSKBN2AV190?fbclid=IwAR389ZML_SfBU70TQDXD2SL2p5BsTwx5kWv7-_FytDBuzm2ZwI7XqvvNwll
 10. <https://www.dw.com/ro/secretul-scoaterii-institutului-cantacuzino-din-joc-ce-se-mai-poate-face/a-56506139>
 11. <https://buletin.de/bucuresti/vaccinul-romanesc-anti-covid-chiar-si-sub-licenta-de-fabricatie-este-aproape-imposibil-sa-se-produca-la-cantacuzino/>
 12. <https://www.digi24.ro/stiri/actualitate/sanatate/cat-de-posibila-este-varianta-producerii-unui-vaccin-anti-covid-in-romania-1448071>
 13. <https://doi.org/10.1080/07388551.2018.1498443>
 14. <https://www.zf.ro/companii/terapia-cluj-demarat-probele-tehnologice-putea-fabrica-romania-19950676>
 15. Author interview with senior staff in the Ministry of Defence.
 16. <https://koronavirus.gov.hu/cikkek/gyorgy-laszlo-szaz-nap-mulva-elindul-debreceni-oltoanyaggyar-letesitese>
 17. <https://hungarytoday.hu/hungary-national-vaccine-production-plant/>
 18. <https://index.hu/belfold/2021/04/26/koronavirus-jarvany-adatok-operativ-torzs-muller-cecilia-gall-kristof-terasznyitas-maszkviseles/>
 19. <https://www.one.org/africa/issues/covid-19-tracker/explore-vaccines/>
 20. <https://elpais.com/sociedad/2021-06-24/cuba-logra-la-primera-vacuna-latinoamericana-con-datos-de-efectividad-al-nivel-de-pfizer-y-moderna.html>;
 21. <https://www.dw.com/es/covid-19-las-vacunas-cubanas-son-una-esperanza-para-am%C3%A9rica-latina/a-58007770>
 22. <https://cu.ambafrance.org/Dr-Vicente-Verez-Bencomo-Chevalier-de-la-Legion-d-Honneur> ; <https://research.uottawa.ca/iss/vaccine-pays-big-first-semi-synthetic-vaccine-children>
 23. <https://english.elpais.com/usa/2021-07-01/cuba-announces-its-abdala-vaccine-is-9228-effect-ive-against-covid-19.html>
 24. <https://www.one.org/africa/issues/covid-19-tracker/explore-vaccines/>

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