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Abstract

Cross-border supply chains and international trade enabled the manufacturing and delivery of billions of vaccine doses to inoculate the world against COVID-19. At the same time, the pandemic revealed how the World Trade Organization (WTO) must change to become more useful in the face of a public health emergency. This paper describes the market failures—especially on the supply side—justifying the domestic subsidies and contracting arrangements used to accelerate vaccine research and development and to increase the scale of vaccine production to save lives, livelihoods, and economic activity during a pandemic. It highlights tradeoffs associated with the US subsidies and the priority-rated contracts written for vaccines through the Defense Production Act under Operation Warp Speed. This case study reveals a rich environment in which cross-border supply chains exacerbate input shortages in ways that constrain vaccine production, highlighting the need for the WTO to embrace new forms of international policy coordination for pandemic preparedness and response. As part of a pandemic treaty, the paper proposes a plurilateral agreement on vaccine supply chain resilience that would include novel and enforceable disciplines for export restrictions, provisions to trigger coordinated subsidies across countries to jointly scale up vaccine output- and input-production capacity, and market surveillance initiatives on supply chain transparency.

JEL Classification: F13

Keywords: COVID-19, Export restrictions, Subsidy policies

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The WTO and vaccine supply chain resilience during a pandemic

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Cross-border supply chains and international trade enabled the manufacturing and delivery of billions of vaccine doses to inoculate the world against COVID-19. At the same time, the pandemic revealed how the World Trade Organization (WTO) must change to become more useful in the face of a public health emergency. This paper describes the market failures—especially on the supply side—justifying the domestic subsidies and contracting arrangements used to accelerate vaccine research and development and to increase the scale of vaccine production to save lives, livelihoods, and economic activity during a pandemic. It highlights tradeoffs associated with the US subsidies and the priority-rated contracts written for vaccines through the Defense Production Act under Operation Warp Speed. This case study reveals a rich environment in which cross-border supply chains exacerbate input shortages in ways that constrain vaccine production, highlighting the need for the WTO to embrace new forms of international policy coordination for pandemic preparedness and response. As part of a pandemic treaty, the paper proposes a plurilateral agreement on vaccine supply chain resilience that would include novel and enforceable disciplines for export restrictions, provisions to trigger coordinated subsidies across countries to jointly scale up vaccine output- and input-production capacity, and market surveillance initiatives on supply chain transparency.

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1. INTRODUCTION

Upon the emergence of a pandemic, new and life-saving medical countermeasures like vaccines are critical. So are the size, speed, and form of government subsidies needed to accelerate their research, development, and scale of production.

In the case of COVID-19 vaccines, international trade played two essential roles. First, cross-border supply chains and imported inputs were needed to manufacture doses. Second, most countries relied entirely on imports to gain access to these new products, having no local vaccine manufacturing facilities. Both roles for trade made enhanced commercial policy cooperation essential. Yet much of the demand for more international policy coordination went unmet, though not for traditional reasons.

Governments intervened in markets too little, not too much. In particular, countries missed out on an opportunity to engage the World Trade Organization (WTO) in novel ways to play a proactive role in pandemic response. This is unsurprising: historically, the WTO has been where governments convened to discuss only how to jointly constrain their use of subsidies, not expand them. In the context of COVID-19 vaccines and international supply chains, that would turn out to be a problem.

This paper contributes to an evolving literature on lessons from COVID-19 for the WTO. Most research to date has focused on diagnosing existing challenges—on WTO provisions for intellectual property (Abbott and Reichman 2020); allowances for export restrictions (Pauwelyn 2020; Sykes 2020); or more broadly, governments' resort to "exceptionalism" arguments to justify policy actions otherwise in violation of WTO rules (Meyer 2020; Arato, Claussen, and Heath 2020). The approach here is similar in spirit to Pinchis-Paulsen (2020): it seeks to address areas where WTO rules may not only be inadequate, but qualitatively where existing guidelines tend to push in the wrong direction in the face of a crisis.

The paper is organized as follows. Section 2 explains the economics of vaccines, identifies the market failures that arise, and makes the case for implementing aggressive economic policies to accelerate vaccine production and increase its scale during a pandemic. It begins with the domestic setting, describing characteristics of novel national policies such as advance market commitments, as well as pull and push contracts, to speed up and to increase the scale of vaccine production (Athey et al. 2022). It then details the fragmented production structure for vaccine

manufacturing during the pandemic, highlighting the role of cross-border supply chains and imported inputs.

As a case study, section 3 describes US policies for COVID-19 vaccine manufacturing under Operation Warp Speed and the priority-rated contracts that emerged through the Defense Production Act (DPA) of 1950. This setting is important because the United States came closest to operationalizing the sorts of novel domestic policies needed to expedite vaccine development and manufacturing during a pandemic. However, the US approach also revealed new challenges to international economic policy cooperation, including input rationing, direct and coordinated subsidization of input provider production capacity, transparency into cross-border supply chains, and clarification of provisions on export restrictions.

Section 4 reviews how vaccine shortages led to concerns over the imposition of explicit export restrictions during COVID-19. It briefly summarizes key lessons from the experiences of the United States, India, and European Union.

Section 5 then presents a proposal for a new plurilateral agreement on vaccine supply chain resilience. Beyond explicit accommodation of national subsidies, the proposed agreement would create a framework that would proactively trigger and coordinate subsidies along the vaccine supply chain, even across countries, to better deal with input shortages. It would demand Members accept a more active WTO Secretariat to which supply chain details would be disclosed to help with advanced stockpiling of inputs as part of pandemic preparedness. During a public health emergency, the Secretariat would also engage more directly with market surveillance efforts needed to help ration scarce inputs more efficiently, diagnose shortages, and then repurpose scarce inputs as they are freed up when some vaccine candidates inevitably fail clinical trials. Critically, the proposal also includes an explicit mechanism to create new and binding disciplines to constrain export restrictions for the vaccine supply chain by harnessing existing WTO norms on reciprocity.

Section 6 concludes by putting this proposal into the context of ongoing WTO and World Health Organization (WHO) negotiations over preparedness as well as a potential pandemic treaty.

2. THE ECONOMICS OF VACCINES AND SUPPLY CHAINS

Economics is a useful tool for understanding how policymakers can create incentives to achieve public health objectives, such as vaccinating the population during a pandemic. Because vaccine markets fail in the absence of government intervention, national governments must alter the

incentives of people and firms. Policy interventions become even more complex and nuanced in the modern global economy, which is characterized by fragmented, cross-border supply chains for vaccine manufacturing.

2.1 VACCINE MARKET FAILURES AND DOMESTIC GOVERNMENT POLICIES

The market for vaccines features failures on both the demand and supply sides.[1] The demand side is relatively straightforward to understand, as the consumption of vaccines generates positive externalities. An individual who takes a vaccine provides uncompensated benefits to society. Some vaccines can break disease transmission. Others limit the severity of the disease, reducing the burden on potentially over-stressed health systems. Without government policy intervention, purely market-based outcomes would result in too few individuals consuming vaccines relative to the social optimum. To help overcome this market failure, governments typically procure vaccines from companies and distribute them to consumers free of charge or at highly subsidized prices.

On the supply side, the market failures for inventing and manufacturing vaccines would prove to be more complex. By the 1990s, the inability to develop vaccines for diseases arising primarily in poor countries—such as malaria, tuberculosis, and certain strains of HIV prevalent in Africa—demanded a new policy approach that spurred novel economic research into the sources of the underlying problems. Decades of failure were linked back to how policymakers struggled to create the right incentives by subsidizing inputs (research and development [R&D]), with informational asymmetries ultimately resulting in governments picking the "wrong" scientists, labs, and approaches to subsidize. Michael Kremer, winner of the 2019 Nobel Prize in economics, and others subsequently pioneered solutions to the problem, such as using advance market commitments (AMCs)—a legal guarantee that fully-funded market for the vaccine would exist in the future—to strike the right balance between incentivizing research and accelerating vaccine development and production.

One supply-side market failure for vaccines is the "hold-up" problem. Suppose a firm is contemplating sinking hundreds of millions of dollars into research, clinical trials, and the building of a vaccine-specific supply chain for production. Once those costs are sunk, the purchaser—almost always a government, as vaccine demand has generally not been left to individual purchasers operating in markets—has an incentive to offer a price for the vaccine that

[1] This section draws especially from Kremer and Glennerster (2004) as well as Kremer (2001a, 2001b).

is only just above the firm's marginal cost of production, but providing no economic reward for having borne the prior risk, and no means of recovering the enormous costs of development. But using backward induction, the firm recognizes the future difficulty it would face recouping the sunk costs of R&D and its vaccine-specific facility. Realizing it will be held up, the firm underinvests in the first place. As a result, too few vaccines are invented, developed, and produced.

To help solve this potential problem, Kremer and others suggested that policymakers provide firms with AMCs and other contracting guarantees to incentivize them to make the investments necessary to invent and deliver viable vaccines.[2] The basics of the AMC approach provided a useful template for understanding supply-side issues that emerged during the COVID-19 pandemic.

2.2 POLICIES TO ADDRESS VACCINE SUPPLY PROBLEMS DURING A PANDEMIC

In the case of COVID-19, supply-side problems were exacerbated by the need to accelerate vaccine development and manufacturing, as well as to incentivize production at a global scale. During the pandemic, a collection of experts, including Kremer, formed the Accelerating Health Technologies group and proposed early and often that these problems be tackled by creative subsidy policies.[3] They recommended that governments contract with vaccine sponsors by relying on insights from the AMC approach and offering specialized forms of "push" and "pull" funding.

Consider the following stylized example, taken from Athey et al. (2022) and substantiated through their formal modeling results (figure 1). During the pandemic, early estimates suggested that the global economy was losing the equivalent of roughly $1 trillion a month in economic output, morbidity, and mortality.[4] In the absence of any vaccine, the economic harm from the pandemic in this example was $24 trillion, or the area given by the rectangle with base 24 months and height $1 trillion per month.

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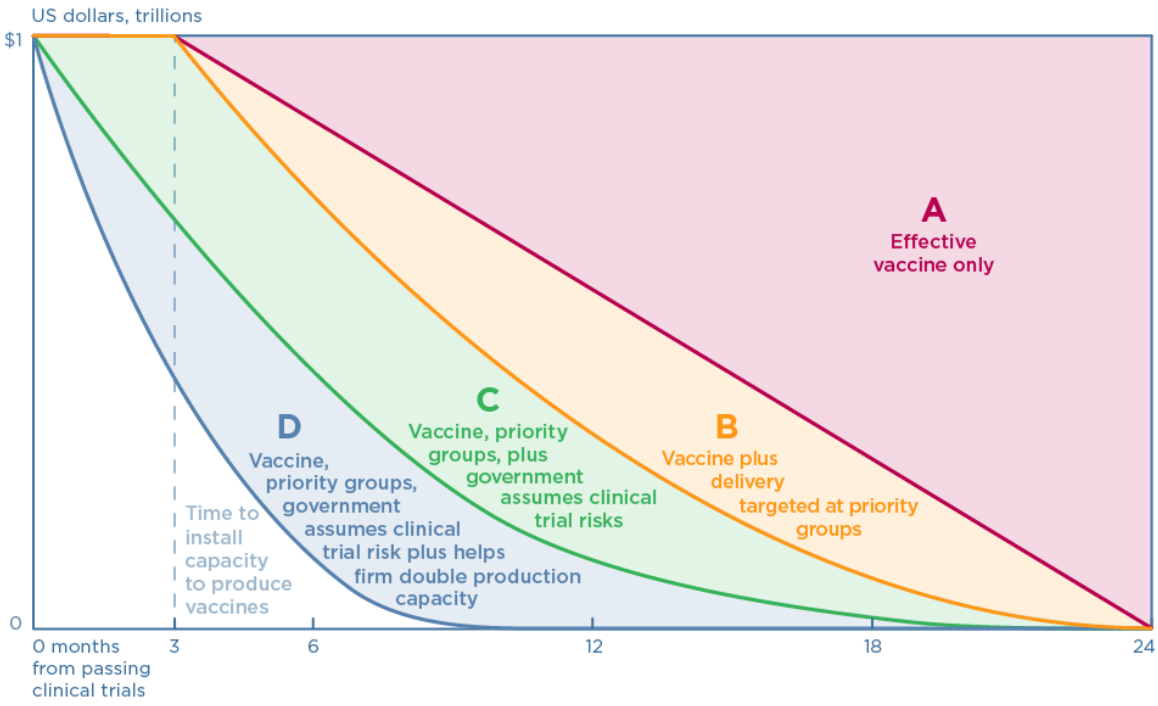
[2] For the application to a pneumococcus vaccine, see Kremer, Levin, and Snyder (2020).
[3] See Susan Athey, Michael Kremer, Christopher Snyder, and Alex Tabarrok, "In the Race for a Coronavirus Vaccine, We Must Go Big. Really, Really Big," *New York Times*, May 4 2020; Eric Budish and Christopher Snyder, "Bigger Is Better When It Comes to Vaccine Production," *Wall Street Journal*, March 17, 2021; Scott Duke Kominers, "World Can Have Covid Boosters and Its First Doses, Too," Bloomberg, September 28, 2021; Snyder et al. (2020); Castillo et al. (2021) ; and Ahuja et al. (2021).
[4] See Cutler and Summers (2020) and Agarwal and Gopinath (2021).

Figure 1

Policies to accelerate and increase the scale of vaccine production limit the global economic and social harm of a pandemic

Time taken to eliminate social and economic costs of a pandemic, by policy choice



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Source: Modified from Figure 1 of Athey et al (forthcoming).

Suppose that eventually a vaccine is invented, makes it through clinical trials, is manufactured, and is distributed to a sufficient number of people to bring the pandemic under control. Let month zero be the time the vaccine passes clinical trials. In this stylized example, assume it takes three months for the firm to install vaccine manufacturing capacity to begin producing doses for global distribution and then another 21 months to vaccinate the world. If these steps proceed sequentially, the pandemic ends two years after the vaccine receives regulatory approval. The exercise examines how different policy choices reduce the economic harm the pandemic imposes on society.

For simplicity, assume that a single firm controls the candidate vaccine technology. The benchmark case involves the firm waiting to install capacity until after it is certain that the vaccine will receive regulatory approval. The firm waits because capacity is costly and sunk: The investment has no alternative use if the vaccine does not pass clinical trials.

In the baseline case, suppose administering the vaccine reduces harm to the population linearly—assume for simplicity that doses are randomly allocated—and the pandemic ends 21 months later, at month 24. In this baseline scenario, the vaccine reduces economic costs (generates benefits to society) given by area "A."

Next suppose that the government better allocates vaccines by targeting priority groups. This distribution could reflect some mix of public health and economic considerations, such as providing early vaccine access to front-line workers and hospital personnel, vulnerable populations with co-morbidities, or even workers in important economic sectors. Better targeting avoids even more losses, given by "B." (The curvature of the new border results from initial vaccinations having a greater marginal reduction of harm than later doses given to lower-priority populations.)

Now consider what happens when the government also has supply-side policy instruments to incentivize when (how early) and how (how many doses) the firm sets up its vaccine production facility. First, suppose the government can convince the firm to establish its production capacity earlier, so that policymakers can begin distributing doses the moment the vaccine is granted regulatory approval, rather than three months later. In this scenario, the policy shifts the risk of the vaccine failing in a Phase 3 trial from the firm to the government. Doing so generates the societal benefit (of additional harm reduction) given by area "C"—the $3 trillion gain from accelerating the end of the pandemic by three months.

Second, suppose the government also has a policy instrument to convince the firm to double the size of its production capacity. Twice as much capacity allows the pandemic to end 10.5 months after doses are first administered rather than 21 months later. This benefit is the reduction of an additional area of economic harm given by area "D."

The benefits of supply-side policies are now evident. Society reaps large gains by convincing the firm to both accelerate manufacturing capacity investments at risk and to significantly expand that capacity beyond what may be in its private, commercial interests. Without these policies, a profit-maximizing firm would wait until after resolution of uncertainty associated with the lengthy Phase 3 clinical trial. Furthermore, if vaccine prices were relatively fixed—as they mostly were during much of the COVID-19 pandemic, in the range of $4–$60 per course, well below their estimated social value of $6,200 per course (Castillo et al. 2021)—the firm has little private incentive to invest and substantially increase production capacity to fill orders more quickly,

especially because there was little concern that competitors would enter the market if it delayed.[5]

How could governments convince firms to start investing in manufacturing capacity in advance of regulatory approval? How could they convince firms to install additional capacity?

In the case of COVID-19, the recommendation was that policymakers subsidize vaccine development by focusing on a mix of "push" and "pull" contracts with firms. Push contracts involve subsidizing inputs to expand capacity early, regardless of whether a vaccine candidate proved successful. Pull contracts reward expedited delivery of doses of approved vaccines. The idea was for governments to provide subsidies across multiple vaccine sponsors and their associated technologies to diversify away scientific risk; in addition, they should do so *at risk*, so that firms could begin building their manufacturing infrastructure in parallel with the Phase 3 clinical trials. Policymakers should also directly contract over production capacity and a delivery schedule—e.g., a specific number of doses arriving by a specific date—and not simply contract over doses that would allow the firm to put their order into a queue.

2.3 VACCINE SUPPLY CHAINS, INPUTS, AND IMPORTS

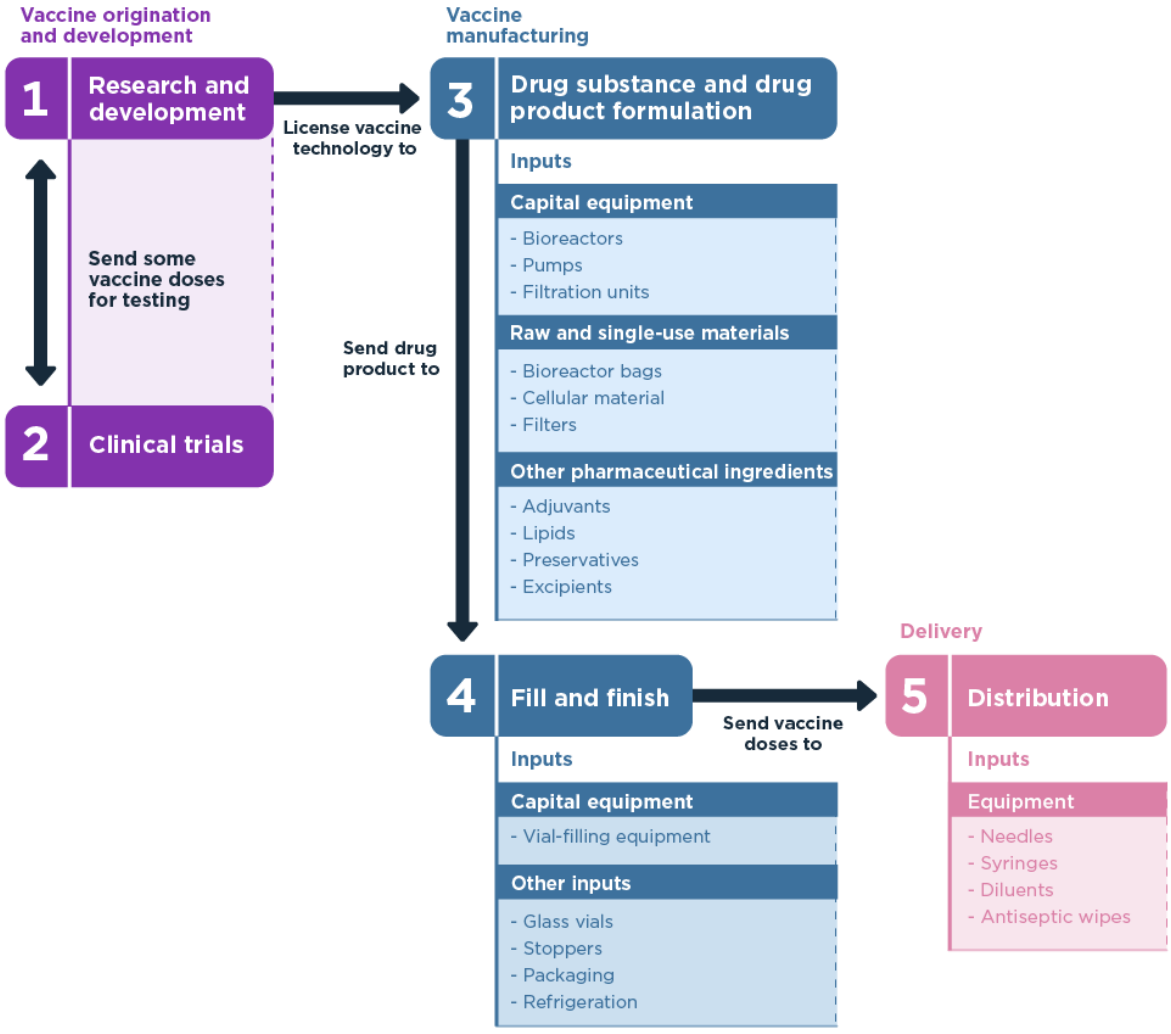
An additional supply-side challenge facing policymakers during COVID-19 arose because of the nature of the vaccine value chain. Getting vaccines from beginning to end involves five basic steps, or fixed costs, as shown in figure 2. The separability of these fixed costs meant that, heading into the pandemic, the pharmaceutical industry had evolved into one characterized by outsourcing as well as offshoring.

The process could be highly fragmented. Scientists at a biotech firm or university might invent a vaccine in step 1 and thus become the vaccine sponsor. A second firm, known as a contract research organization (CRO), might be paid to conduct the costly clinical trials to provide the data that would help the regulator determine whether the candidate vaccine was safe and effective. A third firm, known as a contract development and manufacturing organization (CDMO), would produce the vaccine in a highly specialized plant. A fourth firm—another CDMO—would "fill and finish" the liquid vaccine, putting it into vials, assembly-line style, at a completely different highly specialized plant, and package the vaccines for distribution to health care workers to administer them to the public.

[5] Eric Budish and Christopher Snyder, "Bigger Is Better When It Comes to Vaccine Production," *Wall Street Journal*, March 17, 2021.

Figure 2

Getting vaccines from start to finish involved five main steps



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Note: Stages and inputs depicted illustrate general vaccine production process and are not comprehensive.

Source: Bown and Bollyky (2022).

The industry was characterized by both fragmented production and offshoring, which may have played at least two important roles. First, the manufacturing plants of steps 3 and 4 could be in different countries from each other and from the sponsor that invented the vaccine. Second, specialized inputs that these plants needed to manufacture completely new vaccines from scratch might be available only through international trade.

The nature of the industry thus created additional challenges for ensuring that the supply-side subsidy policies described in the last section would work. Push and pull contracts to convince vaccine sponsors to invest at risk (to get earlier doses) and to increase their production capacity (to get more doses) would be successful only if the sponsor passed those incentives along the entire supply chain, including to different firms (outsourcing) as well as to firms located in foreign countries (offshoring). An input shortage arising anywhere along the supply chain would mean failure of even the most well-designed subsidy policy a government provided to a vaccine sponsor. Getting earlier and more doses meant vaccine sponsors would have to convince the firms owning the manufacturing facilities, as well as those making highly specialized inputs, to expand their production capacity at risk as well.

3. LESSONS FROM US SUBSIDIES UNDER OPERATION WARP SPEED

When COVID-19 hit the United States, the federal government implemented some elements of this approach of subsidizing at risk and contracting on capacity. This section draws from Bown (2022a) and reviews Operation Warp Speed, the DPA of 1950, and the priority-rated contracts that the US government negotiated with companies sponsoring six different COVID-19 vaccines in 2020.

3.1 DIVERSIFICATION, SPEED, AND SCALE

Two of the most important features of US supply-side policy for vaccines were its diversification and the provision of early subsidies. Subsidies to facilitate vaccine R&D began in February and March 2020.[6] Seven different candidates were backed to start. For five—from Moderna, Johnson & Johnson, AstraZeneca-Oxford, Novavax, and Sanofi-GSK—the US government developed explicit elements of the at-risk subsidies and contracting on capacity suggested in section 2. For a sixth candidate, from Pfizer, the government wrote an early procurement-only contract. The US government gave a seventh candidate, from Merck-IAVI, $38 million in April 2020; the candidate did not pass initial clinical trials and was abandoned relatively early.

Some early subsidies helped facilitate the completion of clinical trials, including the expensive, data-intensive, and time-consuming Phase 3 trials, which can require 30,000 or more participants, sometimes with subsidies of $400–$500 million dollars per vaccine candidate. (For biotech companies like Moderna and Novavax that did not have their own manufacturing

[6] The database accompanying Bown (2022a) provides additional information on the timing and details of the contracts with vaccine sponsors.

facilities to make doses for Phase 3 trials, subsidies also covered the costs of outsourcing production to CDMOs.) These US subsidies generated positive externalities for the rest of the world, as regulators elsewhere would not necessarily need to replicate the trials.

Once five of these promising candidates started Phase 3 trials, in the summer and fall of 2020, the United States negotiated contracts for over $1 billion each, including some guaranteed funding to allow firms to begin installing capacity to manufacture 100 million or more doses.[7] These contracts allowed companies to establish vaccine-specific manufacturing facilities and supply chains in advance of regulatory approval by the Food and Drug Administration (FDA), which remained five months into the future at the earliest. Some contracts also included pull-like incentives for speed. The one with Moderna, for example, promised a higher price per unit if the FDA granted the company emergency use authorization by January 31, 2021.

The US government implemented its subsidies by negotiating priority-rated contracts under the DPA with the vaccine sponsors. Legal terms of the DPA required the companies to fulfill US government orders for 100 million or more vaccine doses before firms could start supplying anyone else. DPA also forced vaccine sponsors to pass that same prioritization along their supply chains. Their input providers thus needed to fulfill their orders for specialized equipment and raw materials under these contracts before they could work for anyone else.

Ultimately, the FDA did not authorize three of the candidates (from Novavax, Sanofi-GSK, and AstraZeneca-Oxford) for public use during the key vaccination phase of the pandemic. For those vaccines, the US government received little payoff for its public investment. The US government achieved its public health objective through diversification, which also gave it access to vaccines developed by Pfizer, Moderna, and Johnson & Johnson.

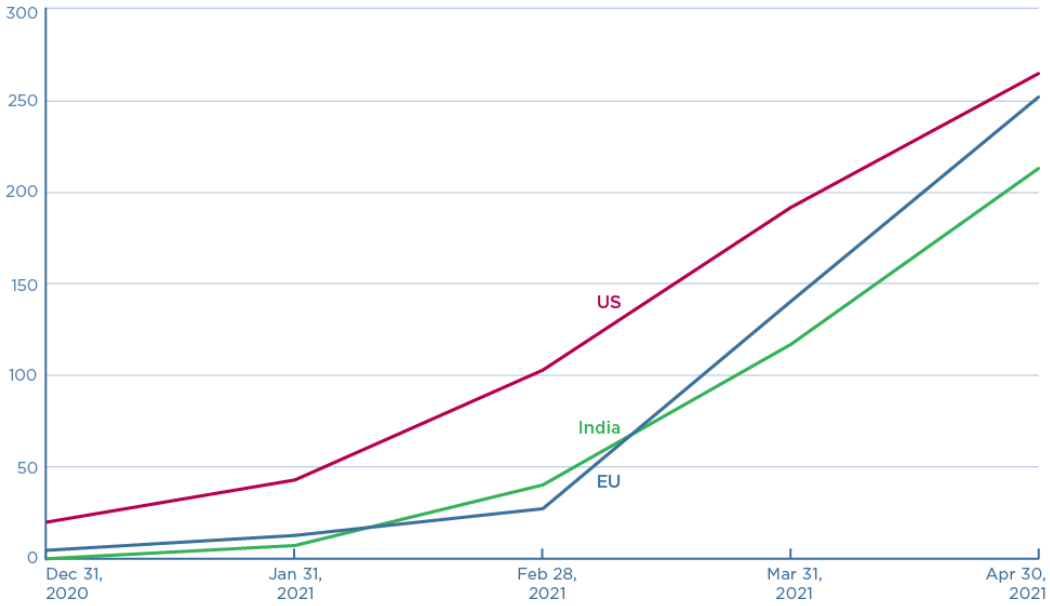
Overall, Operation Warp Speed was a success for the United States, resulting in multiple viable COVID-19 vaccines and millions of doses produced (at risk) early, to be distributed immediately upon authorization. US production bested output from even the European Union and India in

[7] Details of the contracts are unknown, as the publicly available versions are highly redacted. However, the Government Accountability Office (GAO 2021) summarizes its review of the contracts and interviews with officials from Operation Warp Speed (the Department of Defense and the Department of Health and Human Services) and from the companies. The exception to guaranteed at-risk funding in the United States was Pfizer, which negotiated a contract that did not receive a DPA priority rating but with a higher price ($19.50 per dose) for 100 million doses; Pfizer retained the risk if the vaccine failed in clinical trials (Bown 2022a).

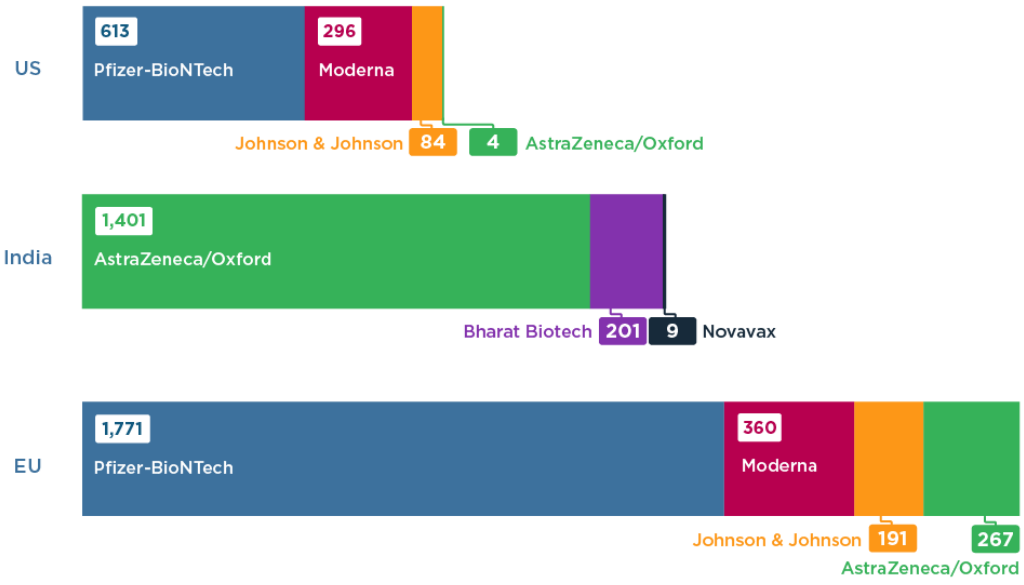
Figure 3

The United States produced a lot of COVID-19 vaccine doses by early 2021, but the European Union and India had more production capacity overall

a. Cumulative vaccine supply by economy, millions of doses, December 2020–April 2021



b. Cumulative vaccine supply by economy and by brand, millions of doses, as of December 2021



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Note: Panel a cumulative totals are as of the final day of each month. Supply estimates based on the amount of vaccine doses delivered to countries as of the last day of that month, not accounting for stockpiles, waste, or doses not yet delivered. Supplying country determined by location of the drug substance facility. Moderna's drug substance facility in Switzerland is included with the European Union.

Source: Constructed by the author with data from Airfinity.

the early and pivotal months of 2021 (figure 3), even though these other economies ended up with much more production capacity and production overall by the end of 2021.

Despite the US success, many experts criticized the $18 billion of US funding in 2020 as being orders of magnitude too small, given the savings—in terms of lives, livelihoods, and economic activity—resulting from accelerating output by a month and/or an adding 100 million more doses to production scale. In their modeling, for example, Ahuja et al. (2021) suggest that the US government should have subsidized more than three times what it did and diversified across 27 vaccine candidates in 2020.

There are at least five practical implications of the US subsidization approach for international cooperation:

First, the funding model shifted substantial financial risk onto the US government and away from firms.

Second, as firms' investment in manufacturing capacity and the creation of new supply chains could take place simultaneously with Phase 3 trials; vaccines granted regulatory approval would have millions of doses available for distribution immediately. Contracts were designed to help capture *some* of area "C" in figure 1 (if not part of "D," depending on whether the contracts encouraged investment in more capacity, irrespective of timing).

Third, the US government "owning" the vaccine sponsor's first 100 million doses and having them delivered on a specific schedule meant it had implicitly contracted on capacity that would potentially generate positive externalities for other buying countries. A buyer that contracts on capacity creates an asset that can be switched over to other buyers after its order has been fulfilled, whereas a buyer that contacts on doses only lengthens the vaccine queue, imposing a negative externality on others (Athey et al. 2022).

Fourth, the major vaccine sponsors created multiple, parallel manufacturing supply chains, in part because those contractual terms prohibited US plants from exporting those first doses (Bown and Bollyky 2022). Paradoxically, the US contracts that incentivized the same vaccine sponsors to install additional capacity in other countries may have also generated positive externalities for the rest of the world, in the form of that forced diversification. Additional geographical diversification could be beneficial in the event of future shocks—such as unexpected imposition of vaccine export controls or manufacturing problems—which might be

country- or plant-specific.[8] One tradeoff, however, was that may have been globally inefficient: Investing to create the same additional capacity at US plants could have led to more learning-by-doing or local spillovers increasing total production yields, resulting in more doses more quickly globally than multiple parallel supply chains.

Fifth, limitations prevented the US government from exporting vaccine doses it was buying under those initial contracts.[9]

3.2 TACKLING INPUT SHORTAGES: PRIORITIZATION, RATIONING, AND SUBSIDIES

Firms could not produce COVID-19 vaccine output if they could not acquire sufficient vaccine inputs. Input shortages would reveal other roles for international economic policy cooperation during a pandemic.

Vaccine inputs were in short supply for many reasons. One was the unexpected surge in demand. Input providers initially had insufficient capacity to supply the dozens of facilities globally in 2020, amidst their sudden clamor to gain access to the same specialized equipment and raw materials needed to manufacture brand new COVID-19 vaccines at the same time (Bown and Bollyky 2022). Another worry was that input-providing companies may not have had sufficient private incentives to invest in the additional capacity that would become unproductive once the pandemic was over, preventing firms from recovering the costs of their investments.

The DPA was also important in helping US vaccine manufacturers deal with the input shortage challenge. Again, the terms of the priority-rated contracts signed with the US government obligated the vaccine sponsors to pass the priority rating along their entire supply chains, implying that those manufacturers would get access to inputs needed to make COVID-19 vaccines before other companies needing the same supplies to make other products.

At the same time, one concern is whether price signals from vaccine manufacturers to input providers—to convince them of the demand surge to trigger input production capacity expansion—were either slow, incomplete, or legally incapable of being sent. Any failure by the

[8] Numerous examples of such shocks have emerged for COVID-19 vaccine manufacturing (Bown and Bollyky 2022). More generally, see Grossman, Helpman, and Lhuillier (2021); Miroudot (2020); WTO (2021a); and Baldwin and Freeman (2022).
[9] The US government's July 2020 contract with Pfizer, for example, stated, "The Government agrees that it will not resell any of the deliverables to any third party."

input supplier to see the positive price signal would attenuate the incentive for them to add production capacity.

In the case of US inputs, one unintended side effect of the priority-rated DPA contracts was that vaccine sponsors could demand inputs to fulfill those orders from suppliers at fixed prices, impeding the price signal (Bown 2022a). Another explanation was the existence of offshoring heading into the pandemic, which may have made it difficult for an input supplier in a foreign country (e.g., the United States) to somehow receive a large enough price signal arriving via demand from a vaccine manufacturer in a different country (e.g., India or Germany), perhaps if there were contracting frictions.[10]

In this environment, governments can overcome such a market failure by directly subsidizing upstream vaccine input providers in addition to downstream vaccine manufacturers. One approach would be to deploy the same sort of push contracts but to make them contingent on expanding input capacity installation (which generates positive externalities), not simply the delivery of vaccine inputs (which generates negative externalities by allocating other input buyers to later in the queue), as described in the context of vaccine outputs in section 2.

One practical challenge, however, involved identifying which input suppliers needed to be subsidized. In 2020, the US government used Operation Warp Speed to subsidize capacity expansion for some input providers located in the United States. It signed push-style contracts with selected companies manufacturing relatively homogeneous inputs, such as glass tubing and vials for fill and finish facilities, as well the syringes and needles needed to administer vaccine doses (Bown and Bollyky 2022). However, subsidizing the expansion of production capacity would prove more difficult for specialized inputs. In October 2020, the US government provided Cytiva—a then recent spinoff from GE Healthcare—with a subsidy of $32 million to expand capacity "for vaccine-related consumable products, such as liquid and dry powder cell culture media, cell culture buffers and mixer bags, as well as hardware including XDR bioreactors."[11] US policymakers described Cytiva as "the primary supplier to many of the companies currently working with the US government to develop COVID-19 vaccines" (see again figure 2).

[10] In a (nonpandemic) model of trade in specialized inputs and offshoring, Antràs and Staiger (2012) find that the lock-in effect results in equilibrium imported inputs being inefficiently low, with subsidies to inputs the optimal policy. Bown, Snyder, and Staiger (2022) examine this pandemic offshoring problem in a formal theoretical model.

[11] BARDA (Biomedical Advanced Research and Development Authority). 2020. "Trump Administration Expands Manufacturing Capacity with Cytiva for Components of COVID-19 Vaccines," News Release, October 13.

At the time the contract was signed, the US government was unlikely to be aware of the full range of input shortages likely to arise, even for US manufacturing plants, given that firms had not yet fully developed their supply chains. The US government had knowledge of some of those input–output relationships through the priority-rated contracts it wrote and had to administer under the DPA (as described next), but it was unlikely to have learned details of Pfizer's input needs, for example, until Pfizer signed its first priority-rated contract under DPA in December 2020.

Furthermore, in 2020, US policymakers had to ration scarce inputs from a number of suppliers, spreading them across a variety of manufacturing facilities. Logistics experts from the Department of Defense—one of the government agencies tasked with implementing Operation Warp Speed— assisted by acting on supply chain relationships and input demand information made accessible through the priority-rated contracts signed under the DPA (Mango 2022). The CEO of MilliporeSigma—a major vaccine input provider whose supplies were being rationed—said that his company was "in nearly daily communication with 'colonels and majors,' the pharmaceutical companies, and their contract manufacturers" and that they were collectively forced "to start making trade-offs when you've got limited supply and limited capacity to focus on the need of the moment."[12]

3.3 IMPLICATIONS OF US INPUT SHORTAGES FOR THE REST OF THE WORLD

Some of the specialized inputs needed by COVID-19 vaccine manufacturers globally may have been available only from US suppliers, at least in the very short run. The Operation Warp Speed subsidies to input providers in 2020 to expand their production capacity may have generated positive externalities for other countries. Nevertheless, companies operating plants in India, such as the Serum Institute of India (SII) and Biological E., or Europe's CureVac were hardly appreciative, instead alleging, beginning in March 2021, that US rationing under DPA was creating an artificial shortage by banning US exports of inputs. Although the data later showed that the United States had not embargoed exports, this episode created diplomatic and political problems, with French President Emanuel Macron even accusing the Biden administration of imposing an export ban on vaccine inputs.[13] Eventually, US policymakers coordinated with the

[12] Riley Griffin, "A Cold War–Era Law and Vaccines," Bloomberg, January 2, 2021.
[13] See Bown and Rogers (2021); Bollyky and Bown (2021); and Sam Fleming, Jim Brunsden, Mehreen Khan, Michael Peel, and Guy Chazan, EU leaders Confront US over Vaccine Patent Waiver Demands, *Financial Times*, May 8, 2021.

European Commission and India to ration scarce inputs to some foreign manufacturing facilities as well.[14]

From a global perspective, these US policies revealed at least two fundamental problems. First, the rationing within the United States was likely inefficient. SII was sourcing inputs from US companies including MilliporeSigma, Thermo Fisher, ABEC, Sartorius, and Cytiva/Pall (Bown and Rogers 2021). US policymakers were unlikely to have insight into the input needs of such foreign manufacturers, some of which may have been producing higher-priority vaccines than US companies that ultimately did not receive FDA approval. (The United States ultimately erred in the other direction, providing scarce inputs to CureVac in spring 2021, even though by the summer the company's poor Phase 3 trial results ruled out its candidate vaccine.) Second, with this missing information, any US subsidy policy designed to tackle the input shortage problem was likely both too small and incorrectly targeted.

This episode underscored the practical challenges to scaling up production capacity along the full vaccine supply chain, especially when parts of that chain are in another country. Policymakers may need to subsidize input providers directly if the price mechanism is unable to transmit the effects a subsidy provided to a vaccine sponsor along the full supply chain. If those input providers are located abroad, one possibility is for foreign governments (in this case, the European Union and India) to identify and then subsidize the firms (in this case, located in the United States).

4. LESSONS FROM VACCINE SHORTAGES AND ALLEGED EXPORT RESTRICTIONS

At least three concerns emerged from COVID-19 regarding potential export restrictions on finished vaccine doses. They involved the United States, India, and the European Union.

4.1 Lessons from the US experience

The United States suffered at least two failures. Despite the US government subsidizing the installation of capacity and committing in advance to purchase all 100 million doses of the initial

[14] See Paola Tamma, "EU Seeks Closer Cooperation with US on Vaccine Supplies," *Politico*, March 6, 2021 and Andrea Shalal, "US to Provide Vaccine Components, Medical Supplies as India Battles COVID-19 Spike," Reuters, April 25, 2021. Cooperation between the United States and the European Union was formalized in September 2021 as a COVID-19 Manufacturing and Supply Chain Taskforce (White House 2021b). US–India cooperation was eventually formalized as part of the "Quad" with Japan and Australia (White House 2021a).

COVID-19 vaccine production, it subsequently failed to distribute some of those doses internationally after having taken delivery. On many grounds—including global public health and equity considerations—that policy decision was suboptimal. However, the US government would have needed to write different contracts to allow it to subsequently redistribute doses—through the COVID-19 Vaccines Global Access [COVAX], for example—to prioritize global public health needs, not only the needs of American citizens.[15]

A separate problem arose because the US government failed to make explicit when companies could export vaccines from US plants, affecting their investment (and thus longer-term exporting) decisions. As Bown (2022a) describes, the uncertainty arose because DPA had given US manufacturers priority access to inputs, but those inputs could be used only to manufacture the vaccines the US government had ordered. [16] Inputs acquired under priority-rated contracts could not be used to manufacture for export. In practical terms, the US government's failure to clarify earlier when Pfizer and Moderna would be able to export from their US supply chains likely tilted company decisions in early 2021 toward marginal investments in capacity expansion more in Europe (Bown 2022b).

4.2 Lessons from India's experience

India's export restrictions on vaccine doses were quite different. The Indian government failed to offer subsidies at risk in 2020 and only began to subsidize Indian vaccine manufacturers in April 2021.[17] SII was able to invest at risk in 2020 only by relying on its own resources and funding from the Coalition for Epidemic Preparedness Innovations (CEPI) as well as the Bill & Melinda Gates Foundation, under an agreement to provide doses to COVAX.[18] However, SII was forced to renege on its COVAX agreement in April 2021, when a wave of cases hit India and the government imposed export restrictions, which remained in effect through October. (According

[15] Eventually, in July 2021, the US government did write such a contract with Pfizer ($3.5 billion for 500 million doses), to procure vaccines that would then be allocated to COVAX for global distribution.
[16] See 45 C.F.R. § 101.38 (a) (2) (i) and 45 C.F.R. § 101.38 (a) (2) (ii).
[17] See Aftab Ahmed, "India to Fund Capacity Boost at Serum Institute, Bharat Biotech as Vaccines Run Short," Reuters, April 19, 2021. In a May 2021 interview, SII's CEO blamed the Indian government for not pre-ordering doses, stating that he had decided against investing in capacity expansion earlier because "there were no orders, we did not think we needed to make more than 1bn doses a year" (Stephanie Findlay, "India's Vaccine Shortage Will Last Months, Biggest Manufacturer Warns," *Financial Times*, May 2, 2021).
[18] See Jeffrey Gettleman, "Indian Billionaires Bet Big on Head Start in Coronavirus Vaccine Race," *New York Times*, August 1, 2020; Gavi, "Up to 100 Million COVID-19 Vaccine Doses to Be Made Available for Low- and Middle-Income Countries as Early as 2021," Press Release, August 7, 2020; Gavi, "New Collaboration Makes Further 100 Million Doses of COVID-19 Vaccine Available to Low- and Middle-Income Countries," Press Release, September 29, 2020.

to data from *Airfinity*, SII manufactured over 600 million doses during those months, none of which were exported.)

On global health grounds, India's decision to prioritize the local population may have been well-founded. What was problematic was that the Indian government not only failed to subsidize the production of those COVID-19 vaccine doses at risk but that when someone else (CEPI) did, the government confiscated doses that COVAX had contracted over that were to be distributed to other countries in need. (One way this was different from the United States is that the US government made clear from the beginning that vaccine doses manufactured under US government contracts would not be available for exporting.)

4.3 Lesson's from the European Union experience

The European Union set up an export monitoring system in late January 2021 to track the destination of vaccine shipments manufactured in the European Union to countries outside the bloc.[19] The move arose partly from the lack of clarity about who in Europe had contracted in advance on capacity (e.g., the United Kingdom)[20] and who had only negotiated procurement contracts on doses (e.g., the European Union). The European Commission faced political difficulties because of its slower vaccine rollout, which partly reflected its failure to subsidize production at risk.

The European Union and the United Kingdom became embroiled in a trade dispute over who had the rights to doses of the AstraZeneca vaccine. The European Union even temporarily invoked Article 16 of the Northern Ireland Protocol for a few hours in late January 2021.[21] Shutting off EU exports of vaccines to the United Kingdom could have turned out disastrously, as the United Kingdom might have retaliated by shutting off exports of vaccine inputs needed to manufacture vaccines in the European Union, such as the lipid nanoparticles essential for the Pfizer-BioNTech vaccine, hurting both sides (Bown and Bollyky 2022). While the European Union did not impose export restrictions in that instance, Italy did block exports of 250,000 doses of the AstraZeneca vaccine destined for Australia in March 2021.[22]

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[19] European Commission, "Commission Implementing Regulation (EU) 2021/111 of 29 January 2011 Making the Exportation of Certain Products Subject to the Production of an Export Authorization," *Official Journal of the European Union*, LI 31/1, January 30, 2021. See also Horn and Mavroidis (2021).
[20] See UK NAO (2020, 24–25).
[21] George Parker, Jasmine Cameron-Chile, and Michael Peel, "EU Pledges Vaccine Controls Will Not Hit UK Supplies," *Financial Times*, January 30, 2021.
[22] Victor Mallet and Jamie Smyth, "France backs Italy's decision to block vaccine exports to Australia," *Financial Times*, March 5, 2021.

The broader EU decision to set up the export monitoring system highlights a problem caused by the lack of transparency by suppliers and the queuing of contracts. Public health would benefit from additional clarity on these types of subsidies and contracts, so that buyers know where they will be placed in a queue and how to write a contract on capacity installation to shorten the queue for others.

5. TOWARD A PLURILATERAL AGREEMENT ON VACCINE SUPPLY CHAIN RESILIENCE

This section describes ways Members could use the WTO to tackle the problem of vaccine shortages during a pandemic. Doing so might also reduce the likelihood (as well as the perception) that countries impose export restrictions—which can result in secondary effects, such as retaliation or noncooperation—when the fundamental policy problem is the shortage itself.

When new Director General Ngozi Okonjo-Iweala took over the WTO, in early 2021, she prioritized WTO engagement in the pandemic, especially on vaccines. In April and June 2021, the WTO convened technical meetings between the private sector and policymakers on topics such as input shortages to help facilitate improved outcomes (WTO 2021b). Unfortunately, by then, it was too late to make much of a practical difference, as most of the policies and supply chain decisions that would determine the vaccine production structure and result in shortages had been set in 2020.

The proposal here is for the WTO to establish a set of pandemic-related vaccine provisions in advance, to be triggered in the event of a public health emergency, codified in a plurilateral agreement on Vaccine Supply Chain Resilience (VSCR). Similar to the way in which the WTO Agreement on Safeguards creates a playbook for how to deal with an emergency situation created by too many imports—imposing trade restrictions, conditional on meeting evidentiary criterion—the VSCR agreement would guide policymakers when a pandemic emergency creates pressures for too few imports (of vaccine output and inputs) and requires activating additional forms of exceptional international policy cooperation.

5.1 CREATING A WTO VACCINE SUBSIDIES PLAYBOOK FOR PANDEMIC PREPAREDNESS AND RESPONSE

The WTO Agreement on Subsidies and Countervailing Measures originally contained a provision on nonactionable subsidies – i.e., subsidies that would not become subject to remedies under dispute settlement or countervailing duties. Its original Article 8 made subsidies

nonactionable if they were for R&D, disadvantaged regions, or the promotion of adaptation of existing facilities to new environmental regulations. In 1999, after five years of provisional application, Article 8 expired (Article 31). There have been calls to reintroduce nonactionable subsidies in WTO agreements in other contexts, such as to incentivize policies to mitigate climate change (Lee 2016). There are also compelling public health and economic reasons to make nonactionable the subsidization of vaccine supply chains during a public health emergency.

Ideally, the WTO would do more by also facilitating the creation of a pandemic playbook for such subsidies. The VSCR agreement would describe the funding, contracting frameworks, and best practices for domestic policymakers to use when confronted with the need to accelerate the vaccine R&D and manufacturing process in such an emergency.

At the moment, no other international organization has been tasked with identifying, let alone updating, this information. The World Organization for Animal Health (OIE) provides one model for how it could be done. The OIE translates scientific insights on animal diseases into best practices that affect trade and commercial policy and that are relied on by the WTO's Sanitary and Phytosanitary Measures (SPS) Agreement and SPS Committee, among others. It maintains scientific commissions, composed of outside subject experts; it publishes (and updates) their recommendations as standards via a legal document referred to as its Terrestrial Code. As one example, chapter 10.4 of the OIE's Terrestrial Code details the latest standards for avian influenza, a recurring disease that often infects commercial poultry farming. The Terrestrial Code develops policy guidelines for countries in the face of outbreaks at home and in trading partners. Information includes when and how to restrict and reopen trade when outbreaks emerge and are then contained. Although governments do not always follow the Terrestrial Code when implementing trade restrictions in the face of animal disease outbreaks, the Code provides a science-based guidebook to help policymakers follow best practices, diffuse trade disputes when they arise, and prevent the outbreak of countless more.[23]

Analogously, a group of independent industry experts, combined with experts in economic policy and public health, would develop guidelines for pandemic-era vaccine manufacturing policy. This Vaccine Supply Chain Resilience Code (VSCRC) would describe the latest insights from AMCs, push and pull contracting with companies. Domestic policymakers would benefit

[23] See, for example, Bown and Hillman (2016, 2017).

from a roadmap to structure incentives to get firms to pursue outcomes to help meet public health objectives when a crisis emerges.

To complement the VSCRC, the WTO Secretariat would work with industry experts and WTO Members to organize information on vaccine facilities and essential inputs and then engage in market surveillance and monitoring. Put differently, the WTO would need to go beyond its current role of *policy* surveillance and venture into *market* (supply chain) surveillance. The closest current example of such an effort is the Agricultural Market Information System (AMIS), which surveilles markets for food shortages by publishing high-frequency data on domestic production, consumption, and stockpiles, and not just changes in trade policies.

With its expertise in data collection and understanding of the role of input–output relationships in supply chains, the WTO could help create a reservoir of information and data on vaccine production facilities and key input providers. It could help identify what inputs could be stockpiled in advance, to be tapped in an emergency. The WTO Secretariat has the capacity to provide a secure platform for sharing and protecting business confidential information, as exhibited in the context of WTO litigation.[24] During the COVID-19 pandemic, CEPI took on some of this survey work for vaccine manufacturing facilities (CEPI 2020).

5.2 RELIEVING INPUT SHORTAGES

Given the nature of cross-border supply chains, the WTO would also play four complementary roles in helping address the inevitable problem of input shortages for vaccine production at the onset of a pandemic. First, it would be the international organization tasked with helping to identify where input shortages might arise. Not all inputs can be stockpiled; a vaccine to tackle a novel disease is likely to require at least some new specialized inputs. There will therefore be an inevitable period of input shortages. Diagnostics would require liaising with policymakers in WTO Members, updating its survey of vaccine manufacturers to identify and cross-check the input providers in their supply chains, and building from the baseline information on preparedness already on hand (see previous section).

Second, the WTO would provide the forum to help coordinate the rationing of scarce inputs to their most beneficial use during the very short run, when dire shortages are inevitable. Alongside the early ramp-up of production facilities during COVID-19, the United States

[24] See, for example, the proprietary data and information used as evidence in the lengthy and politically contentious Boeing–Airbus disputes between the United States and the European Union that the WTO Secretariat was trusted to keep secure.

rationed scarce inputs domestically and ultimately extended its rationing, at least informally, to EU member states and India. In normal times and for normal goods, if markets are perfectly informed and competitive, the price mechanism allocates inputs to their most productive use. Relying on prices may not be possible at the onset of a public health emergency. Even if so, it is still important to define the market failure, so that it is clear why policy intervention and rationing are needed to improve upon market-only outcomes, as well as when the policy intervention should end. One candidate argument is that the WTO and its Members—via their regulatory authorities at the FDA, the European Medicines Agency (EMA), as well as the WHO—might have better information than the market as to which vaccine candidates are closer to regulatory authorization and where the impact of allocating the marginal input in short supply would have the greatest marginal benefit to society.

Third, the WTO would provide a forum for policymakers in key vaccine supply chain countries within which to coordinate subsidies—including contracting on capacity expansion of input providers—along the full, cross-border supply chain. Failing to do so may result in the sort of input shortages that holds back vaccine production.

Fourth, the WTO would work to reallocate resources when some are inevitably made available because of newly realized information from failed Phase 3 trials. In July 2021, CEPI created the COVAX Marketplace to do so for COVID-19 vaccines (CEPI 2021). The WTO would be better positioned to do so on a permanent basis, given that some repurposing of inputs may require policy coordination across markets and different legal jurisdictions.[25]

5.3 MAKING RULES FOR EXPORT RESTRICTIONS ENFORCEABLE

A final step is to create new and binding disciplines to prevent export restrictions across the vaccine supply chain. Doing so is imperative, and also possible, but is unlikely to materialize without explicit linkages to enforceable provisions on subsidies to accelerate the timing (at risk) and scale of vaccine production, as well as an explicit understanding on the distribution and sharing of vaccine doses once they are produced.

The experience of COVID-19 revealed the problems. A country like the United States, for example, may not want to constrain the use of domestic legal guarantees to output arising from its publicly funded, potentially at-risk investments without some certainty that it will get access

[25] Indeed, other opportunities to repurpose entire supply chains during COVID-19—such as the case of CureVac—might materialize if there were more creative policymaking with firms to help break and remake firm-to-firm contracts (encourage efficient breach) and new subsidy arrangements (Bown 2021).

to vaccine doses. Yet, the Indian case identifies the costs of failing to act. In the future, "foreign" entities (like CEPI) may be less likely to subsidize at-risk investments abroad without an enforceable legal guarantee that vaccine exports resulting from that investment will not be confiscated. Finally, even domestic entities may be unlikely to invest without additional clarity over nonapplication of export restrictions—recall the exporting uncertainty facing Pfizer and Moderna in early 2021 for its operations in the United States (Bown 2022b).

In theory, existing WTO rules and norms could be sharpened to create mutually beneficial and enforceable plurilateral disciplines on export restrictions for the vaccine supply chain, even during a pandemic.[26] Doing so involves explicitly operationalizing the reciprocity principle that has been used implicitly to keep markets open generally, through the process of dispute settlement and authorized retaliation for violations of WTO rules.[27]

In the case of vaccines and a pandemic, countries would sign up ex ante to be part of the plurilateral agreement on VSCR. Participating would require voluntarily revealing the input–output linkages between vaccine manufacturers and their suppliers described earlier. The agreement would also commit to a distribution scheme among members for vaccine doses produced by members. It would also specify guidelines for members to trigger, coordinate, and finance subsidization of a diversified portfolio of vaccine candidates at risk, at scale, and along their entire supply chains. Economies with many vaccine manufacturing facilities—such as the United States and the European Union—would invest in multiple candidates at risk. Smaller countries might have the facilities to invest in just one. Vaccine input–supplying countries would subsidize expansion of that capacity as well.

Some of those at-risk investments in vaccine production facilities will not pay off after Phase 3 trials. At that point, external enforcement is required to keep countries committed to exporting, as once information is revealed about which countries have operational and valuable facilities producing vaccines authorized after Phase 3 trials, those countries will have a unilateral incentive to renege, in order to keep doses for themselves via export restrictions. Any earlier promise that they will not do so becomes time inconsistent. This time-inconsistency problem is why credible external enforcement is needed.

The incentive to restrict exports can be thwarted through collective external enforcement. Signatories to the plurilateral agreement must agree to trigger a high enough cost if any

[26] This discussion builds on some of the ideas originally proposed in Bollyky and Bown (2020).
[27] For an introduction to the economics of reciprocity under the WTO, see Bagwell and Staiger (2002).

unilateral defection occurs. The most punishing form of enforcement might be for the input-providing countries to cut off exports of those inputs if the first country cuts off exports of finished vaccine doses. The identity of these input-providing countries—i.e., that the agreement would task with retaliating via new export restrictions —would be known, because of the voluntary revelation of input–output linkages described earlier.[28] (The threat of this retaliation is what would keep markets open. Recall how the interdependence between the United Kingdom and the European Union kept vaccine inputs [lipid nanoparticles] and outputs [vaccines] flowing between the two in early 2021, even during the most difficult political times.)

During a pandemic, where speed is paramount, a full WTO dispute settlement proceeding to litigate the issue of whether a country imposed an export restriction would take too long, even if the system were functioning.[29] The enforcement threat must be made operational quickly and with certainty. It requires safeguards, so that retaliation is not triggered inadvertently. Avoiding misunderstandings of the sort that arose during the COVID-19 pandemic regarding what is a demand-induced input shortage and what is an export restriction on inputs is an additional motivation for increasing transparency and establishing guidelines for appropriate contracting and subsidy behavior.

Paradoxically, not all countries will be eligible for the plurilateral VSCR agreement. The agreement requires interdependence for enforcement to work. Some countries might be unwilling to be sufficiently interdependent (if, for example, they have the industrial capacity to host an entire vaccine supply chain domestically). Although such a country would surely gain ex ante from the diversification associated with being part of a group that is investing across a wider portfolio of vaccine candidates, its unwillingness to submit to external enforcement upon the resolution of uncertainty associated with the Phase 3 trial means that it cannot be part of a functioning plurilateral agreement. It cannot participate because its defection could not be prevented, to the detriment of the rest of the group, which would cause the agreement to break down.[30]

[28] To reduce the likelihood of political alliances reducing the retaliatory threat, the inputs could be stockpiled in an escrow account administered by the WTO Secretariat, with the Secretariat tasked with withholding inputs if the first country imposed export restrictions on vaccine output.
[29] A separate concern, not addressed here, is that the original dispute settlement process no longer works because Members can appeal Panel decisions "into the void" due to a non-functioning Appellate Body (Bown and Keynes 2020).
[30] This problem could potentially be overcome with external enforcement through a nontrade instrument. As an extreme example, the other members of the plurilateral agreement could threaten to withhold virus

In the end, the starting point for a plurilateral agreement could be a large group comprised of small, but open and interdependent, economies. The Ottawa Group is a collection of WTO Members that did convene during COVID-19 to propose a Trade and Health Initiative, though not in the form outlined here (WTO 2020).[31]

6. CONCLUSION

During the COVID-19 pandemic, the motto of vaccine supply chain subsidies became "spend billions to save trillions." The United States was one of the few countries to subsidize the acceleration of vaccine development much at all. Yet, the rest of the world did not fail to act because the United States had a monopoly on COVID-19 vaccine intellectual property or technology: The Pfizer-BioNTech vaccine was developed in Germany, the AstraZeneca vaccine was developed in the United Kingdom, and the Johnson & Johnson vaccine was co-developed in the Netherlands. Plants to manufacture these and other COVID-19 vaccines emerged all over the world. Indeed as early as the fall of 2020, vaccine technology was licensed to firms in India, Thailand, Argentina, South Africa, Mexico, and other developing countries, many of which would manufacture tens of millions of doses of COVID-19 vaccines by the end of 2021.[32] The main policy challenge was how to incentivize production of those doses on a quicker time schedule and at larger scale.

With cross-border supply chains, the failure to subsidize investment in productive capacity at a very early stage (even before regulatory approval has been granted) can be traced in part to unmet demand for the novel forms of international cooperation described here. Unfortunately, there is little evidence that WTO negotiators have recognized this issue or the need to change their approach.

The WTO's 12th Ministerial Conference (MC12) in Geneva in June 2022 produced only marginal progress. Ministers agreed to a limited waiver on intellectual property rights protection for COVID-19 vaccines (WTO 2022a). But even with a different form of technology transfer for vaccines during a pandemic, virtually all of the supply-side challenges that prevent the acceleration and scaling up of vaccine production would still exist. Furthermore, the Ministerial Declaration coming out of the MC12 included nothing on subsidies or their coordination and

samples from the vaccine export–restricting country in a way that would affect its ability to make future vaccines. See, for example, Fidler (2007).

[31] The Ottawa Group does include Japan and the European Union, the latter of which could be plausibly self-sufficient, in terms of its vaccine supply chain.

[32] See figures 3 and 5 in Bown (2022a) as well as Bown and Bollyky (2022).

indicated little more on transparency (WTO 2022b). As its approach to the problem of input shortages, the WTO also continues to focus only on policy surveillance, thus ignoring market surveillance and supply chain diagnostics. The declaration also included only a modest effort on export restrictions. Unfortunately, without the full suite of policies—vaccine distribution, coordination of subsidies across countries and along the vaccine supply chain, policies needed to tackle input shortages—such an approach to export restrictions is likely to be unenforceable and insufficient to thwart governments from acting in their own unilateral self-interest at the next sign of crisis.

The COVID-19 pandemic revealed the urgent need for change in some forms of international trade governance. For example, a public health emergency may require compensating a country that gives up scarce inputs (through rationing to facilities located abroad) with guarantees of some of the resulting benefit (a share of the doses manufactured from those scarce inputs). In normal times, for normal goods, and in the absence of shortages or binding capacity constraints, the benefits of this exchange are achieved largely through the price mechanism, markets, and international trade. In a pandemic, some of those price incentives become severed and markets can disappear, especially in the very short run. This requires other institutions step in to fill the gap, helping to intermediate and facilitate the benefits arising through comparative advantage, specialization, scale economies and ultimately international exchange.

Although countries did not utilize the WTO in this way during COVID-19, it remains the best-positioned international organization to facilitate these novel forms of international economic policy coordination during a public health emergency. While the WHO has launched a process to develop a "pandemic health treaty,"[33] many of its elements for medical countermeasures like vaccines should build upon the institutional framework as well as commercial policy expertise, principles, and experiences embodied in the WTO.

[33] World Health Organization. "World Health Assembly agrees to launch process to develop historic global accord on pandemic prevention, preparedness and response," News release, December 1, 2021.

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