



POLICY FORUM

COVID-19: ECONOMICS

Market design to accelerate COVID-19 vaccine supply

Build more capacity, and stretch what we already have

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Each month, COVID-19 kills hundreds of thousands of people, reduces global gross domestic product (GDP) by hundreds of billions of dollars, and generates large, accumulating losses to human capital by harming education and health (1–4). Achieving widespread immunization 1 month faster would thus save many lives and mitigate short- and long-run economic harm. Although the value of vaccines may seem obvious, government action and investment in vaccines have not been commensurate with the enormous scale of benefits, with many countries not likely to achieve widespread immunization until the end of 2022.

We estimate below that installed capacity for 3 billion annual vaccine courses has a global benefit of \$17.4 trillion, over \$5800 per course. Investing now in expanding capacity for an additional annual 1 billion courses could accelerate completion of widespread immunization by over 4 months, providing additional global benefits of \$576 to \$989 per course. This dwarfs prices of \$6 to \$40 per course seen in deals with vaccine producers, indicating the wide gap between social and commercial incentives. We urge govern-

ments and international organizations to contract with vaccine producers to further expand capacity and encourage measures described below to “stretch” existing capacity (such as lower-dose regimens) and efficiently allocate courses (such as a cross-country vaccine exchange).

Our analysis involves two exercises, first estimating the global benefits from vaccine capacity already in place, then estimating the benefits of undertaking additional capacity investment starting now (see supplementary materials for all data and methods). The enormous estimates from both exercises provide a wake-up call relevant for the current pandemic—that it is not too

Vaccine capacity equals speed, which has enormous value in a pandemic. Vials of the COVID-19 vaccine developed by AstraZeneca move along the production line at the Serum Institute of India plant in Pune, India.

late to invest in more capacity—and future pandemics—that preparations to shorten delays in rolling out vaccines, treatments, and other countermeasures at global scale could prevent enormous harm.

VALUE OF CAPACITY IN PLACE

In our model, a unit of capacity is defined as the fixed investment needed for one course per year of a regulatory-approved COVID-19 vaccine, including production lines as well as complementary investments necessary to get shots into arms (e.g., input-supply chains, transportation logistics, and medical staff at administration sites). Our discussion focuses on production capacity because it involves the most economic risk and lead time, so may be the rate-limiting step.

Capacity already in place, some of which was installed “at risk” before clinical trials were completed, is more valuable than capacity that comes online later because it can produce vaccine courses without delay. Some credit for the extent of capacity in place can be ascribed to advance contracts that many countries signed with firms. Typically, firms only install capacity at commercial scale once a vaccine is proven safe and effective, creating a delay of at least 6 months between clinical approval and large-scale vaccination. By signing contracts in advance of clinical approval, governments shoulder some of this risk and incentivize firms to install capacity earlier.

It is difficult to pin down the level of capacity currently in place precisely. We take 3 billion courses of annual capacity as our baseline, with half coming online in January and half in April. This baseline is high relative to current production but low relative to best-case production plans for 2021 announced by firms succeeding in phase 3 clinical trials (table S1). We trace out global benefits for a range of capacities around this baseline, from 1 billion to 5 billion annual courses.

The International Monetary Fund (IMF) estimates global GDP losses from COVID-19 of \$12 trillion during 2020–2021 (2), an average monthly GDP loss of \$500 billion. More comprehensive harm estimates—including education and health losses—are multiples larger. For example, comprehensive harm in the United States has been estimated (3) to be over five times the projected GDP loss. We use \$1 trillion (double the IMF estimate of GDP losses) as a conservative measure of comprehensive global monthly harm.

Global value of vaccine capacity

GLOBAL CAPACITY (BILLION COURSES)	GLOBAL BENEFIT (TRILLION \$)		TIME TO 70% VACCINATION (MONTHS)	
	GDP ALONE	COMPREHENSIVE	HIGH-INCOME COUNTRIES	WORLD
1	5.3	10.5	31.5	66.0
2	7.5	15.0	16.5	33.7
3	8.7	17.4	11.5	23.0
4	9.4	18.8	9.0	17.6
5	9.8	19.7	7.5	14.4

Vaccine capacity assumes ramp-up such that half of the indicated capacity is available starting January 2021 and the remainder starting April 2021. First two columns estimate global benefit in monetary terms from specified capacity over a 24-month period. Last two columns estimate time until 70% of high-income countries or world population is vaccinated using available capacity. Allocation of capacity to countries of different income levels is based on reported bilateral deals and assumes that global capacity is fully utilized until the target of 70% of world population is vaccinated. Calculations are based on the model outlined in the text and detailed further in the supplementary materials.

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We estimate that having 3 billion courses of annual capacity provides a global benefit of \$8.7 trillion in GDP alone and \$17.4 trillion in comprehensive benefits (see the first table), an average of over \$5800 per course. More capacity provides more value and reduces the time to complete widespread vaccination, but at a decreasing rate, the next billion courses of capacity contributing about half as much as the billion before.

Projecting allocations of vaccine courses across countries on the basis of reported bilateral deals with vaccine manufacturers, given that high-income countries (HICs) have signed a disproportionate share of the deals, we estimate that completing widespread vaccination in the world will take about twice as long as in HICs. A mathematical consequence is that an increase in capacity generates a larger absolute reduction in time to vaccination for the world than for HICs. For example, an increase from 3 billion to 5 billion courses of capacity would speed up vaccination by 4 months for HICs but by nearly 9 months for the world.

The value of capacity comes not just from large scale but also from early availability. If all 3 billion courses of annual capacity were available in January instead of half not ramping up until April, comprehensive benefits in the first table would be \$1.3 trillion higher. The huge estimates of monthly harm cited above mean that our finding that capacity in place has huge value is not very sensitive to our modeling assumptions.

VALUE OF ADDITIONAL CAPACITY

The case for additional investments may be less clear than it was for initial investments given that we are a year into the pandemic and investing now generates additional capacity only with a lag. Even assuming a lag of several months, we find that additional investment can still be extremely valuable. Adding capacity for 1 billion annual courses to the baseline 3 billion would avert \$576 billion in comprehensive losses if the capacity comes online in July and \$989 billion if the capacity comes online in April (see the second table) and would speed up completion of widespread vaccination by over 4 months. Although April or July may be ambitious targets for new capacity, they might be achieved

by creative “stretching” measures described below or repurposing of existing vaccine capacity, if not a well-resourced effort to build new capacity.

The substantial value of investing in additional capacity is driven by two key factors. First, although a large fraction of health benefits may be obtained by vaccinating a small proportion of the population (e.g., health care workers and the elderly), obtaining full economic benefits may require reaching the broader population. Second, it is far from certain that current capacity is sufficient to fulfill

income countries. Investing in accelerating vaccines can pay for itself many times over from reduced fiscal costs alone. Even if governments’ savings on fiscal expenditures is a fraction of the GDP benefit from additional vaccines, this exceeds any estimate of the cost of capacity inferred from COVID-19 deals. The World Bank has made \$12 billion of financing available to fund vaccination (among other priorities), but most has not been taken up. Using these funds to expand vaccine capacity would have high net benefits for developing countries and their donors.

Global value of additional 1 billion annual courses of capacity

SCENARIO	ADDITIONAL GLOBAL BENEFIT (BILLION \$)	SPEED-UP TO 70% VACCINATION (MONTHS)			
		GDP ALONE	COMPREHENSIVE	HIGH-INCOME COUNTRIES	WORLD
April 2021	2	970	1940	4.5	10.2
	3	495	989	2.1	5.0
	4	270	540	1.2	2.9
July 2021	2	636	1273	3.5	9.2
	3	288	576	1.4	4.3
	4	129	257	0.6	2.3

First two columns estimate global benefit in monetary terms from 1 billion courses of capacity, coming online April or July 2021, added to specified baseline capacity. In all scenarios, baseline capacity ramps up such that half is available starting January 2021 and the remainder starting April 2021. Additional global benefits (which can be added to baseline from the previous table to compute total benefits) are computed over a 24-month period. Last two columns estimate the speed-up of vaccination of 70% of high-income countries or world population relative to baseline time from the previous table. See the previous table for additional notes.

best-case production plans. The less baseline capacity that materializes, the more valuable is adding to that capacity. If baseline capacity is just 2 billion courses, the economic benefits of 1 billion additional courses grow to \$1.3 trillion to \$1.9 trillion, and widespread vaccination is sped up by over 9 months.

Our estimates may understate the need for additional vaccine capacity if boosters prove necessary, some existing capacity is nullified by vaccine-resistant strains, or some existing production lines are hampered by technical glitches. Even if there is only a small chance that new capacity will be needed for these or other reasons, additional capacity is valuable in expectation because it provides insurance against the worst pandemic outcomes.

The IMF estimates that governments are spending around \$1.5 trillion a month on fiscal support during the pandemic (5), which may lead some to feel that their budgets are too strained to pay for vaccine capacity. Even now, only a small amount of vaccine capacity has been installed to serve low- and middle-

rather than only specifying a quantity of vaccine courses. An advance contract for the delivery of a set number of courses for a set price may provide too little incentive for speed if not structured thoughtfully (6). Unless bound by an explicit capacity commitment or delivery date, the firm’s commercial incentives are to save costs by investing in smaller capacity, fulfilling the order over a longer period but generating the same revenue from the contract. Although buyers could try to eliminate delays by specifying deadlines for delivery, these may slip (as many existing contracts have) unless backed by late penalties. However, firms are unlikely to accept contracts with substantial penalties that reflect the full social cost of delay.

The danger of signing a contract on courses is that the country may find itself at the end of a queue with a long wait for life-saving vaccines. Provisions to shorten this wait may harm other countries that are pushed back in the queue. Contracts that

MARKET-DESIGN PRINCIPLES

The enormous global benefits of additional vaccine capacity (\$576 to \$989 per annual course by our estimate) compared to prices of \$6 to \$40 obtained by vaccine producers in deals to date suggest a wide gap between social and commercial incentives for vaccine capacity. Economic principles of market and contract design can help bridge the gap, allowing society to realize the large potential gains at reasonable cost.

Contract on capacity versus output

Contracts should include provisions for installing new capacity dedicated to the buyer

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expand capacity can benefit both the signer and other countries by increasing the rate at which the queue is served.

Paying up front for capacity may end up being cheaper for governments. Imagine a future pandemic in which firms are again striving to develop vaccines with no assurance of success. By paying up front for capacity for vaccines still at risk of failure, governments can bear most of the risk. Paying for courses conditional on success can end up inflating government expenditures owing to the private information firms have on their costs (7) or probabilities of success (8).

Relax supply-chain constraints

Governments should invest in supply-chain capacity for intermediate goods needed to make vaccines. Rapid expansion of vaccine manufacturing capacity creates a spike in demand for inputs like glass vials, lipid particles, and bioreactors. Meeting this demand requires an expansion of input capacity. The spike in demand may be temporary, however, after which the added input capacity may be left idle. To justify an expansion of input capacity commercially, a short-term price surge may be needed. Social constraints on pricing during a pandemic may preclude surges (9), however, resulting in shortages of intermediate goods. Public agencies may need to intervene in the input market, building input stockpiles in anticipation of manufacturing scale-up or signing contracts for the installation of new input capacity.

Solicit bids

Some commentators contend that all feasible capacity is being brought to bear on COVID-19 vaccines; further expansion will be prohibitively expensive, if not impossible, in a reasonable time frame. The need for additional capacity is too urgent to take these contentions for granted. By soliciting bids from firms for capacity expansion (whether by installing new factories, repurposing existing ones, or finding ways to increase yield), governments could discover potential opportunities and their costs, allowing them to make informed investment decisions. Our analysis suggests that governments should aim to install substantial capacity even if they must pay a higher price for marginal units of capacity than in deals to date.

USING CAPACITY EFFICIENTLY

The COVID-19 pandemic is far from “business as usual” in the vaccine market, calling for creative ideas to stretch capacity.

Dosing regimens

Proposals to stretch existing capacity by delaying the second of two doses in a course, by using lower-dose regimens, or by giving

only one dose to those previously infected with the virus have a similar effect on supply as a direct increase in capacity. These proposals could have large potential benefits; thus, investigating their medical appropriateness is worthwhile.

Vaccine trials

Some vaccines may be more effective than others against new strains of COVID-19. New vaccine trials could help determine the best matches, enabling vaccines to be distributed to the appropriate regions where new strains are spreading. New vaccine trials could also be used to test which dosing regimen is most efficient in the effort to stretch vaccine capacity. Phase 3 trials for efficacy could be conducted head-to-head with no need for an unvaccinated control group, allowing trials to be conducted at large scale—even embedded in national vaccine rollouts—leading to faster results.

Utilizing lower-efficacy vaccines

Given the value of speed in a pandemic, using a less effective vaccine available now can be better than waiting for the later arrival of a more effective one (fig. S2). Similar logic suggests that lower-dose regimens can have large benefits to a country by getting more vaccine to citizens more quickly even if the regimens reduce the efficacy of individual vaccinations somewhat.

Cross-country vaccine exchange

As more vaccines are approved, given the scramble to secure bilateral deals, the nature of the fair allocation protocol adopted by COVAX (a global initiative to promote access to COVID-19 vaccines), and rapidly changing circumstances, some countries may end up with vaccine allocations that are not optimally matched to their needs. For example, some countries may have difficulty handling vaccines requiring ultra-cold storage or may be willing to trade off a small reduction in efficacy for a large increase in quantity. Countries allocated several vaccines may prefer to simplify logistics by consolidating on one or two.

To facilitate efficient allocation across countries, a vaccine exchange mechanism is under consideration by COVAX. The mechanism would enable countries to engage in mutually beneficial trades of vaccine courses. Centralized market clearing will help aggregate the willingness of all countries to trade, thus maximizing gains from trade and minimizing waste of scarce vaccine courses.

Similar mechanisms have been used successfully in other contexts where gains from trade are substantial, yet traditional cash markets are inappropriate and fairness concerns are paramount (10, 11). This

setting, however, offers specific challenges. Allowable trades must satisfy regulatory approval, indemnification at the country level, and COVAX goals for population coverage. By incorporating such safeguards, an exchange can maximize efficiency, minimize waste, and ensure an equitable allocation.

UNPRECEDENTED CAPACITY

Even though unprecedented vaccine capacity has been put in place for COVID-19, expanding capacity yet further would generate substantial global benefits. Standing manufacturing capacity that can be repurposed quickly to produce vaccines and complementary inputs has a very high social value, in the current pandemic and in expectation of outbreaks to come. Capacity can even be an antidote to conflicts over distribution—which countries get scarce vaccines first and which people—by speeding up widespread vaccination. But markets will not deliver this capacity on their own. ■

REFERENCES AND NOTES

1. L. Boone, “Coronavirus: Living with uncertainty,” *ECOSCOPE*, 16 September 2020, <https://oecdscope.blog/2020/09/16/coronavirus-living-with-uncertainty/>.
2. G. Gopinath, “Reopening from the great lockdown: Uneven and uncertain recovery,” *IMF Blog*, 24 June 2020, <https://blogs.imf.org/2020/06/24/reopening-from-the-great-lockdown-uneven-and-uncertain-recovery/>.
3. D. M. Cutler, L. H. Summers, *JAMA* **324**, 1495 (2020).
4. E. A. Hanushek, L. Woessmann, “The economic impacts of learning losses,” *OECD Education Working Paper* 225 (2020).
5. IMF, Database of Fiscal Policy Responses to COVID-19, January 2021; www.imf.org/en/Topics/imf-and-covid19/Fiscal-Policies-Database-in-Response-to-COVID-19.
6. M. Kremer, J. Levin, C. M. Snyder, “Designing advance market commitments for new vaccines,” *NBER Working Paper* w28168 (2020).
7. C. M. Snyder, K. Hoyt, D. Gouglas, T. Johnston, J. Robinson, *Health Aff. (Millwood)* **39**, 1633 (2020).
8. A. Ahuja et al., “Preparing for a pandemic: Accelerating vaccine availability,” *NBER Working Paper* w28492 (2021).
9. E. Budish, G. Cachon, J. Kessler, A. Othman, *J. Econ. Perspect.* **21**, 37 (2007).
10. E. Budish et al., *Oper. Res.* **65**, 314 (2017).
11. C. Prendergast, *J. Econ. Perspect.* **31**, 145 (2017).

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