

What Governments Should Do to Prevent Shortages of Medically Critical Products in Future Pandemics

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Introduction

This chapter uses the case of personal protective equipment (PPE) shortages in the United States as an example to motivate governments around the world to consider their strategies on how to manage the vulnerabilities in supply chains of medically critical items needed in a pandemic. The United States is the wealthiest economy globally, with a sophisticated healthcare system. The Global Health Security Index in 2019 and 2021 ranked it as having the best potential performance for pandemic preparedness (see Chapter 1). Even so, there were severe shortages of PPE and ventilators in the country in 2020 when COVID-19 emerged. Hence, the failure of the United States in this area provides sobering lessons for other jurisdictions. This chapter first highlights the PPE and ventilator shortages before examining the underlying causes and then making recommendations on measures to ensure supply chains of critical products can quickly respond to future pandemics and other major public health emergencies.

In 2020, the coronavirus SARS-CoV-2 put the entire world on notice with the COVID-19 pandemic, which continued into 2021 and 2022 with several waves and variants. In 2022, the Omicron variant rapidly drove a new phase of infections in many jurisdictions, including ones that had done well earlier to contain the virus. Over this period, COVID-19 created a worldwide health crisis not seen since the 1918 influenza pandemic. According to the World Bank, the world's real Gross Domestic Product (GDP) shrank by 3.4 per cent in 2020 relative to 2019, compared to a growth of 2.6 per cent in the previous year.¹ The US economy also shrank by 3.4 per cent year on year, while the Euro area and Japan experienced drops of 6.4 per cent and 4.6 per cent, respectively.

Economic consequences aside, COVID-19's toll on people was very high in many countries. By the end of July 2022, there had been over 572 million reported cases of infection. In May 2022, the United States has passed more than one million

1. World Bank, 'Global Economic Prospects', June 2022, <https://www.worldbank.org/en/publication/global-economic-prospects>.

COVID-related deaths, and the World Health Organization reported 15 million excess deaths worldwide over the two years from January 2020 to December 2021. Other estimates were even higher.² The sheer scale of the pandemic underscores the need for accelerated development and deployment of vaccines and drugs as preparation for future pandemics and access to medically critical products, such as PPE.³

The COVID-19 pandemic disrupted global supply chain operations from factories to ports, warehouses, and retail outlets. Severe shortages of PPE and ventilators in many countries revealed vulnerabilities in the supply chains of critical products at a time of acute need.⁴ The severity of PPE shortages was a surprise, particularly in wealthy economies that supposedly had longstanding stockpiles and sound preparedness systems.

As demand for hospital care surged, frontline healthcare workers in many places had the same complaint—they were highly exposed but inadequately protected—and yet, they were the ones to help people survive contagion. *The Lancet* reported that healthcare workers were three times more likely than the general population to test positive for COVID-19.⁵ PPE shortages are not just a worker's rights and an occupational health issue but a systemwide health challenge. Without proper protection, frontline healthcare workers are exposed to risks that make them more likely to become ill. Their falling ill leads to a decline in the number of healthcare professionals when the demand for care intensifies, thus reducing the quality of care and weakening the healthcare system.

Beyond healthcare workers, PPE shortages compromise mitigation measures, especially facemasks, which are crucial in reducing community transmission. Panic buying from the public everywhere in the world exacerbated the problem. COVID-19 has made it crystal clear that PPE availability is essential for responding to future pandemics effectively. Governments, hospitals, clinics, and corporations producing and selling PPE must rethink their supply chains. The public, too, has a role to play.

The above observations motivate us to structure this chapter as follows. We identify four underlying causes for PPE shortages based on the observed government response during the COVID-19 pandemic, and propose six recommendations for governments that involve all stakeholders to address these causes.

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2. For excess deaths, see World Health Organization (WHO), '14.9 Million Excess Deaths Associated with the COVID-19 Pandemic in 2020 and 2021', 5 May 2022, <https://www.who.int/news/item/05-05-2022-14.9-million-excess-deaths-were-associated-with-the-covid-19-pandemic-in-2020-and-2021>. Others estimated deaths could have been as high as 18 million: David Adam, 'COVID's True Death Toll: Much Higher Than Official Records', *Nature*, 10 March 2022, <https://www.nature.com/articles/d41586-022-00708-0>.
 3. We focus on medical PPE such as medical masks (surgical and N-95 masks), eye protection equipment (face shields and goggles), gloves, gowns, and coveralls, etc.
 4. Based on a survey of 121 medical facilities in 2020, the WHO reported that fewer than 15 per cent of these facilities have access to the PPE they need (IFC (2021)).
 5. Long H. Nguyen, David A. Drew, Mark S. Graham, Amit D. Joshi, Chan-Guo Guo, Wenjie Ma, et al., 'Risk of COVID-19 among Front-Line Health Care Workers and the General Community: A Prospective Cohort Study', *Lancet Public Health*, 31 July 2020, [https://doi.org/10.1016/s2468-2667\(20\)30164-x](https://doi.org/10.1016/s2468-2667(20)30164-x).

Shortages of PPE during the Pandemic

COVID-19's high transmissibility and rapid spread resulted in many cases around the world requiring hospitalisation. Medical workers needed large quantities of PPE. Shortages stoked public fear and anxiety. The facemask shortage peaked in March 2020 in the United States, while news coverage of PPE shortages (facemasks, N-95 masks, medical gowns, etc.) and ventilators peaked the following month. Regardless of the media report peaks, PPE shortages were not resolved even by the late summer in the United States. In August 2020, 77 per cent of medical facilities in the United States had no supplies of one or more types of PPE. Earlier, from March to August 2020, two types of medically critical products were in severe shortage: facemasks and ventilators.

As COVID-associated hospitalisations skyrocketed in April 2020 and July 2020, the demand for PPE surged in the United States to protect healthcare providers. Prolonged shortages, especially of N-95 masks, have been linked to over 300 deaths and 60,000 infections among US healthcare workers by May 2020. The United States Centers for Disease Control (USCDC) initially recommended frequent hand washing and disinfecting surfaces as vital preventive measures. Then the USCDC further suggested facial covering and social distancing in early April. As different cities issued mandates requiring face coverings to slow the spread of COVID-19, demand for facemasks (mainly surgical masks) increased dramatically, leading to severe shortages.

Experts estimated a minimum need for an additional 45,000 invasive and 77,000 non-invasive ventilators in April 2020, considering the number of ventilators in stockpile or storage and the percentage of COVID-19 patients in intensive care units (ICUs) in need of invasive or non-invasive ventilators. On top of these shortages, over 2,000 ventilators in the US stockpile had either expired or were faulty and therefore unusable. Similarly, some states received unusable masks, gloves, ventilators, and other essential equipment from the national stockpile that had expired, rotted, or became otherwise non-functional. By the end of August, doctors and nurses were still reusing single-use N-95 masks and experiencing shortages of face shields and gloves.

Healthcare spending in the United States in 2019 was 17.7 per cent of GDP, by far the highest in the world. Wealthy countries like Germany, France, Japan, Sweden, and the United Kingdom spent between 10 and 12 per cent of GDP in 2019. China's spending that year was 5.4 per cent of GDP. Moreover, the country had warnings about a lack of preparedness. Despite the colossal healthcare budget and these prior warnings, Americans were shocked by PPE shortages for an extended period in 2020. Naturally, they raised questions about the United States' preparedness to respond to pandemics and other disasters. Indeed, the pandemic preparedness simulation in 2019, called the Crimson Contagion, had already noted shortages of PPE and ventilators, and highlighted other serious problems (see Chapter 9).

Four Causes for PPE Shortages

The COVID-19 pandemic showed that the supply chains for PPE and ventilators are highly vulnerable to disruption. While the media focused on complaints from health-care workers and the authorities' chaotic response to the shortages, the shortages were only *symptoms* of much deeper problems. We propose *four causes* to explain why the United States suffered from severe PPE and ventilator shortages—these issues should also be relevant to other jurisdictions.

Lack of long-term commitment

Whether geographically small or large, every country needs a long-term commitment to maintaining a stockpile of critical items. However, priorities and the level of commitment are often influenced by the day's politics. The United States' Strategic National Stockpile (SNS) was created as a warehouse of medical supplies, drugs, and vaccines.⁶ It is overseen by the Department of Health and Human Services (DHHS) in coordination with the Department of Homeland Security. During the swine flu epidemic in 2009, the PPE distributed from the SNS—including some 85 million N-95 respirators—were not replaced. In 2011, then-President Barack Obama failed to get Congress to approve funds for replenishment. In 2012, Congress cut SNS funding by 10 per cent, and during the Ebola (2014–2015) and Zika (2015–2016) outbreaks, only half of the requested funding was supported by Congress. Individual states may also have built stockpiles. For instance, California amassed a considerable stockpile, including ventilators, under Governor Arnold Schwarzenegger in 2005. However, the stockpile was dismantled by Governor Jerry Brown in 2011 as a cost-cutting measure to reduce the state's budget deficit.

While managing the annual budget for preparedness to acquire PPE items is relatively simple, managing a stockpile of medical equipment for the long-term can be challenging because it requires significant investment in inventory management systems and personnel to ensure all items remain in good working condition. Even in the United States, the SNS inventory management system had not been updated for several years. Expired and faulty inventory was discovered only when urgently needed, suggesting that the SNS programme had not been consistently managed. Without knowing the exact number of functioning units in the stockpile, the authorities could not respond to disruptions in a time-efficient manner, thereby putting healthcare workers and the public at risk.

6. The Strategic National Stockpile is a massive inventory-based approach for demand surges caused by public health emergencies. Suppose a community experiences a large-scale public health incident in which the disease or agent is unknown. In that case, the intent is to send a broad range of pharmaceuticals and medical supplies from strategically located warehouses throughout the United States in 50-ton containers to any state within 12 hours of the federal deployment decision.

Excessive reliance on overseas suppliers

The United States is the world's largest importer of facemasks, eye protection, and medical gloves, making it highly vulnerable to disruptions in the supply chains of PPE. Before the COVID-19 pandemic, PPE was considered a commodity that competes purely on price. Hence, it was cost-efficient for producers such as 3M, Dupont, and Honeywell to offshore (or outsource) the manufacturing of PPE to lower-cost countries, such as China, Malaysia, and Vietnam. Table 8.1 summarises the PPE trade flow among top importing and exporting countries as of 2019.

The global PPE market relies on global trade. However, the COVID-19 pandemic created a new wave of protectionism in 2020, with governments of twenty-four countries, including Germany and France, taking steps to ban or limit the export of PPE and medicines as cases surged in those countries.

Table 8.1: Top importing and exporting countries of PPE in 2019

PPE Products	Top Importing Countries	Top Exporting Countries
Masks (surgical and N95 masks)	US (34%), Japan (10%), Germany (8%), others (48%)	China (44%), Germany (7%), US (6%), Vietnam (5%), other (38%)
Eye protection (face shields and goggles)	US (29%), Canada (6%), Australia (6%), other (59%)	China (59%), US (6%), Germany (5%), other (30%)
Gowns and coveralls	US (37%), Germany (6%), France (6%), other (51%)	China (41%), France (9%), Vietnam (6%), other (44%)
Gloves	US (20%), Germany (20%), UK (6%), other (54%)	Malaysia (25%), Thailand (18%), China (18%), Germany (10%), other (29%)

Source: IFC Report, 2021.

Poor supply chain practices

The outsourcing of production overseas was not accompanied by proper risk management measures, even when the federal government was the purchaser. There was poor supply chain visibility of the supply sources. With severe shortages of PPE arising from the COVID-19 outbreak in 2020, the federal government eased regulations on vendor competition. It provided over US\$1.8 billion to hundreds of unvetted contractors by the end of May. Federal agencies, states, local governments, and hospitals rushed to compete for supplies, and other countries were also looking to purchase more PPE—the result was the world's largest grey market in PPE and sky-high prices. Unethical and opportunistic suppliers cropped up to make a fortune, often without delivering quality products, if at all. Some imported products were found to be substandard. For example, the National Institute for Occupational Safety and Health found that 60 percent

of sixty-seven different types of N-95 masks imported from China failed to provide adequate protection, offering as low as 24 per cent filtration instead of the required 95 per cent. Also, over 1,300 Chinese medical suppliers, including 217 N-95 mask manufacturers, used false addresses and non-working numbers in their registrations with the Food and Drug Administration (FDA). The problem was bad enough for the Chinese government to establish a new system of quality controls for exports of various medical supplies on 10 April 2020, including PPE products. The Chinese government was concerned that bad actors could negatively impact the whole PPE exporting industry.

The pandemic exposed how poorly various firms and the authorities had managed their supply chains. Many firms did not even know who their distant suppliers were. Based on a 2018 Deloitte survey,⁷ some two-thirds of more than 500 procurement leaders from thirty-nine countries have limited or no visibility beyond tier-one suppliers. The FDA and hospital procurement systems also have virtually no supply chain visibility of their sources. The current FDA regulations require PPE manufacturers—for instance, 3M and Honeywell—to report only the locations of their factories rather than their domestic and overseas production capacity. Healthcare providers cannot manage their procurement risk without supply chain visibility. Providers cannot vet and track their suppliers to prevent adulteration and other quality issues without knowing their suppliers' identities. Consequently, time and resources will be wasted during a crisis such as during the COVID-19 pandemic.

Lack of capability for product design, development, and manufacturing

US President Ronald Reagan adopted supply-side economic policies in 1981, which called for tax cuts and deregulation of domestic markets. At the same time, China's 1978 economic reform created a perfect partnership: US corporations could offshore (and eventually outsource) their production to China by leveraging lower labour costs, and China could boost its economy by attracting outside investment. As China improved productivity, quality, and cost-efficiency, it became the 'factory of the world' for many goods. China became the largest producer of many items, including pharmaceutical ingredients (API) and PPE. While other low-cost producers have emerged, such as Malaysia and Vietnam, China remained the key exporter of PPE products. By contrast, decades of offshoring and outsourcing have hollowed out the manufacturing sector in the United States. By 2018, the share of manufacturing employment had dwindled to below 5 per cent of the US population. COVID-19 showed the difficulty of rapidly ramping up domestic production.

7. Deloitte, 'Two in Three Procurement Leaders Have Limited or No Visibility Beyond Tier One of Their Supply Chain', 26 February 2018, <https://www2.deloitte.com/uk/en/pages/press-releases/articles/procurement-leaders-have-limited-o-no-visibility.html>. In the same vein, Choi et al. (2020) reported that, based on a survey conducted by Reslinic in late January and early February after the Covid-19 outbreak in China, 70 per cent of the 300 respondents said they were trying to identify which of their suppliers were in locked-down parts of the country.

During the pandemic, many US firms could not get PPE orders filled from their usual Chinese suppliers. This was because China had to first secure its supply of PPE after resuming manufacturing operations from its prolonged shutdown due to the COVID-19 outbreak and essentially locking down the country from 23 January 2020. In fact, with a new coronavirus first emerging in China in late 2019, China's demand for PPE increased. China not only restricted PPE exports but also imported a substantial portion of global PPE supplies in January and February 2020.

COVID-19 also showed how a pandemic can be an inflection point in the global political economy. As outbreaks emerged in different countries, various countries sought to corner the dwindling supplies. Besides China, other international producers of PPE, including Taiwan, Germany, France, and India, also restricted exports, contributing to much higher costs for those products worldwide. Even when Chinese factories could produce orders again as COVID-19 eased in China, shipping products to the United States and elsewhere was a significant challenge because global supply chains had essentially broken down. Governments worldwide closed borders and ports, imposed quarantine requirements on ocean freight personnel, and flights were greatly reduced.

Consider two examples of inadequate capability for producing PPE. When the supply from China looked uncertain, the apparent solution was domestic production and the following makeshift solutions:

Ventilators: In late March 2020, the United States government estimated that there would be severe shortages of both invasive and non-invasive ventilators. President Donald Trump used the *Defense Production Act* to ask US manufacturers to create consortia to produce ventilators quickly.⁸ For example, automaker General Motors Company and Ventec Life Systems, a medical equipment maker, formed a partnership to build ventilators at a General Motors' plant in Kokomo, IN.⁹ The consortium shipped 600 ventilators by mid-April and delivered 30,000 ventilators through the end of August to the DHHS. While such partnerships were needed at a critical time, the rushed project resulted in mechanical ventilators with basic features that could not fully support a patient's breathing, as there was little time to plan appropriately for design and production.

Facemask production: Considering the severe shortage of facemasks, the United States government asked two clothing companies, Hanes and Brooks Brothers, to retrofit their domestic factories to produce masks and gowns for medical professionals. Although basic facemasks are easy to make, a non-woven material from micro- and

8. Federal Emergency Management Agency, 'Defense Production Act', accessed 14 September 2022, <https://www.fema.gov/disasters/defense-production-act>.

9. At the same time, Michigan-based Creative Foam Corp. and Minneapolis-based Twin City Die Castings, both auto industry suppliers, repurposed their capacity to provide parts at high volume for the GM-Ventec endeavor. At first, the consortium planned to produce 30,000 of Ventec's flagship product with 700+ components for which it had identified most of the suppliers. The government balked at the \$1 billion price tag. Hence, GM and Ventec switched to a more straightforward design with half the cost, but only the single ventilator function without oxygen-related features.

nano-polymer fibres using a conventional technology called melt blowing is needed for surgical¹⁰ and N-95¹¹ masks to create filters to stop germs or minute particles from entering or exiting. The United States had limited capacity to make melt-blown fabric and could not quickly expand the production of melt-blown material domestically. The expensive equipment for making melt-blown fabric (approximately US\$4 million each) was also in short supply. Due to worldwide shortages of surgical and N-95 masks, China suspended its exports of masks and melt-blown fabrics between late February and late March 2020, although exports had mostly resumed by April and export volume more than doubled compared to pre-pandemic levels. In March 2020, South Korea also temporarily banned the export of melt-blown material. The ban was lifted only in August when the in-country supply stabilised relative to domestic demand. Therefore, Hanes and Brooks Brothers could only manufacture basic masks, not the surgical or N-95 masks necessary to protect healthcare workers.

Thus, the lack of capability severely hampered the United States' response to the pandemic, especially regarding PPE shortages.

What Governments Can Do to Prepare Better for Future Pandemics

Government policy is essential to ensure adequate PPE and other medical supplies during emergencies. The example of the United States and the four root causes above contain lessons for stakeholders in other countries too. There is no single approach to secure the supply of PPE in both a time-efficient and cost-effective manner. Relying on stockpiling alone would be too costly and impractical. Focusing on domestic supply chains is not sustainable either, because of sharp demand swings. Developing capabilities takes commitment and a long-term coordinated plan. Therefore, any country needs to develop a 'proactive' plan that is based on a combination of the following strategies to prepare for future pandemics:

Develop an industrial policy

The shortages of PPE and ventilators should serve as catalysts to develop an industrial policy that can guide and focus on certain products and develop the requisite capabilities to deploy resources in time of need. During the decline of the automobile industry in the early 1980s, Labour Secretary Robert Reich argued that the United States should develop an industrial policy that focused on certain business segments to regain international competitiveness.

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10. A proper surgical mask is usually made of three layers: an outer hydrophobic non-woven layer, a middle melt-blown layer, and an inner soft, absorbent non-woven layer. The outer layer is intended to repel water, blood and body fluids; the middle melt-blown layer is designed as the 'filter' to stop germs from entering or exiting the mask; and the inner layer is intended to absorb water, sweat and spit.
 11. An N-95 mask is a respiratory protective device designed to achieve a very close facial fit and very efficient filtration of airborne particles. Unlike the surgical mask, the edges of the N-95 respirator are designed to form a 'seal' around the nose and mouth.

While not presenting a comprehensive industrial policy, President Joseph Biden has consulted with different departments for recommendations on strengthening the supply chains of vulnerable products.¹² The departments that took the lead for individual supply chains were the Department of Commerce on semiconductor manufacturing and advanced packaging; the Department of Energy on large capacity batteries; the Department of Defense on critical materials and minerals; and the DHHS, particularly its agency the FDA, on pharmaceuticals and APIs. The recommendations included steps to strengthen domestic manufacturing capacity for critical goods, recruit and train workers to make critical products, to invest in research and development that will reduce supply chain vulnerabilities, and work with US allies and partners to strengthen collective supply chain resilience. However, low-margin PPE was not included as a category. Low-margin PPE often suffers the worst shortages when demand surges in a major public health emergency. The only way to produce such low-cost, low-margin products profitably is to outsource production of these products to low-cost economies.

It is necessary to have an 'ecosystem' of designers, R&D centres, engineers, production engineers, and technicians to develop capabilities that can be deployed to create production capacity for critical products in times of need.¹³ To do this, the government should engage the private sector and university research centres and provide the incentives necessary for the development and training of personnel with the requisite capabilities. Rather than just focusing on the products per se, different parts of the ecosystem should coordinate to improve the products and to develop manufacturing processes, as well as flexible capacity that could divert capacity to produce medical equipment to make ventilators and PPE when demand surges. Although there is domestic capacity for some types of PPE, for instance masks, the cost is substantially higher relative to imports, so either different production methods are needed, or the costs have to be effectively subsidised to keep a minimal capacity alive.¹⁴

Consider the case of iHealth Labs, the California-based subsidiary of Chinese manufacturer Andon Health that produced at-home COVID rapid test kits for the US government in 2022. Andon Health agreed to produce US\$1.8 billion worth of test kits, which was five times its typical annual revenue.¹⁵ Despite its small size, Andon Health was able to scale up due to its flexibility and capability to mobilise its regional supply chains in China.

12. The White House, 'Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth', June 2021, <https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf>.

13. This notion of standby capability is also known as 'Industrial Commons' (Pisano and Shih 2009).

14. Joe Nocera, 'Why American Mask Makers Are Going out of Business', *New York Times*, 5 March 2022, <https://www.nytimes.com/2022/03/05/business/dealbook/american-mask-makers.html>.

15. Josh Nathan-Kazis, 'Why the U.S. Contracted with a Chinese Covid Test-Kit Maker You've Never Heard Of', *Barron's*, 3 March 2022, <https://www.barrons.com/articles/covid-19-test-maker-ihealth-andon-health-51646318989>.

By the same token, the US government will have to ensure there is a diversity of supply chains within the country that can be called up to meet a demand surge in a pandemic. For PPE production, America Makes (www.americamakes.us) is an Ohio-based non-profit organisation that 'supports the transformation of manufacturing in the United States through innovative, coordinated additive manufacturing and 3D Printing Technology Development and Transition, and Workforce and Educational Development'. Its members include government departments, private companies, and universities. For example, America Makes seeks to coordinate 3D printing capability with the FDA and the Veterans Health Administration to design a 3D printed mask approved by the FDA. Essentially, by coordinating different people with different expertise, America Makes enables the creation of approved PPE designs that can be manufactured with additive manufacturing capability within the country. In addition, America Makes has developed a knowledge-sharing platform (Digital Storefront) that shares the latest information with its members.¹⁶ To a certain extent, America Makes is an ecosystem with standby capabilities that can be deployed to leverage 3D printing technology to develop and produce products when needed.

Education and job opportunities for students also need to be considered. For instance, after decades of offshoring and outsourcing manufacturing to benefit from lower costs, the United States need to significantly beef-up its overall industrial production capacities and capabilities. Many US students shy away from STEM (science, technology, engineering, and mathematics) as there had been fewer job opportunities in those areas. Currently, the United States produces around 500,000 STEM graduates per year, whereas China produced over 4.7 million since 2016. Not having enough STEM graduates results in not having enough talent for designing, developing, and producing equipment and technical products domestically. Unless there is a long-term commitment from the government, it will be challenging for the United States to re-establish these capabilities.

Long-term commitment is needed for manufacturing as well, especially for long-term manufacturing contracts, particularly when the demand is in the form of a highly uncertain surge. For example, 3.5 billion masks were needed annually during the pandemic, but demand will drop heavily during normal times. Also, while there was a panic to quickly produce ventilators in March 2020, there was an oversupply of ventilators at the end of August 2020 when less invasive treatments became more effective. In response to the ventilator oversupply, the US government cancelled the remainder of its contract with medical technology manufacturers.

16. The Storefront is 'an online platform where members can access member-exclusive information, project data, and intellectual capital assets, including project deliverables and artifacts along with their association to the Technology Roadmap'.

Encourage a 'hybrid' supply chain structure

During the first year of the pandemic, the annual demand for protective masks in the United States was 3.5 billion, or roughly 100 times more than the amount in the SNS. It is unrealistic and impractical to store billions of N-95 masks that expire after 3 to 5 years. Therefore, the government needs to develop standby capabilities with private sectors and universities and estimate the time needed to convert capability into actual production capacity. Given the urgency during times of crisis, this conversion time may be too long.

Therefore, it is necessary to develop a stop-gap solution to buy time while converting capability into capacity. Such a solution calls for a hybrid supply chain structure that supports domestic firms to sustain their global supply chains that serve the healthcare markets around the globe. At the same time, state governments should encourage firms to bring back at least some of their offshore manufacturing capacity, just like Texas and South Carolina are already doing.

Clearly, reshoring manufacturing for certain high-tech products requires the development of the previously aforementioned capabilities. Some firms, such as 3M and Honeywell, can certainly expand their supply chain operations for many PPE products in the United States. However, due to the sharp swings in the demand for these products, the US government may need to provide economic incentives, making it economically viable for a larger number of firms to expand domestic production. Using a combination of global and domestic supply chains, a company can cost-effectively produce products by leveraging its global supply chain operations in normal times and by shifting its operations to its domestic supply chain in a time-efficient manner when responding to a pandemic or some other public health emergency. Therefore, a 'hybrid' supply chain structure offers flexibility for the firm to operate its supply chain in a cost-effective or time-efficient manner.

Still, some challenges need to be considered:

Reverting to offshore purchasing before the next pandemic: With facemasks being imported to the extent of 90 percent or more before the pandemic, there was little capacity in the United States for making masks. The few small, focused manufacturers who had persisted did well during the pandemic in 2020–2022. However, the moment the pandemic is declared to be officially over, all indications are that hospitals will revert to their suppliers in China and elsewhere. To prevent these domestic manufacturers from going bankrupt, a possible solution is for the government to purchase masks made in the United States at the federal and state level or to support manufacturing costs.

Shifting PPE demand towards Asia: There are projections that Asia will increase demand for PPE over 2022–2025 as adoption increases in a continent with a population that is nearly eight times that of North America, currently the main source of demand for PPE. As such, there would be a greater impetus among global manufacturers at least to produce in the continent where they will experience demand rather than move facilities to North America. To counterbalance this trend, the US government—likely the

federal government—will have to support a minimal level of domestic manufacturing capacity to enable them to be cost-competitive with Asian suppliers.

Supply chain raw material: Even if capacity is created domestically, there is a chance that raw materials or intermediate products will be imported. One example is non-woven fibre. When Hanes tried to manufacture N-95 facemasks in 2020, it discovered that the critical component of non-woven fibre had to be imported as there was no domestic capacity. Eventually, the company resorted to making essential masks rather than the preferred N-95 ones. To ensure sustainable production of N-95 masks domestically, a possible solution is for the government to provide R&D support to develop new materials and innovative production processes.

Actively manage stockpile inventory

Once the hybrid supply chain structure is established, the government can estimate the domestic production capacity of the domestic supply chain for producing critical products in times of need. Knowing this production capacity and the corresponding response time for production and distribution, the government can then determine the amount of inventory that the national stockpile needs to store. In addition to always maintaining the right inventory level, DHHS needs to conduct periodical audits, inspections, and rotations to ensure all stored units are usable.

By establishing standby capability, developing domestic supply chains, and keeping the right amount of PPE and medical equipment inventory, the authorities will be better equipped to respond to future pandemics. Additionally, the authorities can run stress tests and simulations to identify potential gaps throughout the entire ecosystem.

Encourage innovation

Currently, PPE such as surgical and N-95 masks are considered commodity products that compete on cost. As such, reshoring the production of PPE can be a risky venture when government purchases are based on the lowest cost. Consider the ill-fated investments in US facemask production. The severe shortages of N-95 masks in 2020 created investment opportunities for domestic production. When the number of monthly COVID-19-related deaths shot up in January 2021,¹⁷ the orders for domestically made masks exploded. However, the orders for them vanished after China began exporting more masks at a much lower price. By September 2021, the American Mask Manufacturer's Association estimated that up to ten out of twenty-nine domestic mask manufacturers would go bankrupt. Domestic production cannot be sustained if the purchases continue to focus on procuring PPE at the lowest price because domestic

17. Whet Moser, 'The Deadliest Month Yet', *The Atlantic*, 2 February 2021, <https://www.theatlantic.com/health/archive/2021/02/january-pandemic-deadliest-month/617898>.

manufacturers are not cost-competitive due to higher wages and regulations. Therefore, to encourage domestic production, the procurement process must take the product's value (e.g., quality, full lifecycle cost, and environmental cost) into consideration. Doing so can create incentives for domestic companies to develop and produce innovative PPE products. For example, domestic firms can design PPE to fit different body and face shapes to increase comfort and protection. Designing *reusable* PPE made from biodegradable materials can reduce hazardous waste.¹⁸

Encourage individual responsibility

Preparing for future pandemics should be everyone's responsibility, not just the government's. Specifically, citizens can help curb the spread of future viruses by taking various precautionary measures (e. g., masking, social distancing, hand washing), enabling contact tracing, and participating in the requisite standards of testing and quarantining. Through participation, citizens can reduce the spread of the virus so that the demand for hospitalisation and PPE will not surge as quickly as it did during COVID-19. Public cooperation can buy time for developing more effective responses (e.g., adequate supply of the requisite materials) and for developing better treatments and vaccines. However, good and consistent communication from the authorities will be needed to galvanise the public at critical times.

The large-scale availability of at-home rapid test kits can make individual responsibility easier to bear as people would be able to test themselves at home and take steps to avoid spreading the virus.

Encourage the development of online platforms for response

In addition to developing the physical supply of PPE, online platforms can be considered when designing a coordinated response to identify and match supply sources and demand locations quickly. For instance, getusppe.org is an online platform to match the supply and demand of PPE in the United States. During the crisis, three young New Yorkers created Invisible Hands (invisiblehandsdeliver.org) to match volunteers with seniors and other at-risk groups in need of food and medication. In just two weeks of going online, the site attracted 7,300 volunteers who completed 600 deliveries in New York and New Jersey.

Once all these elements are implemented, we envision the United States and other countries can respond to a future pandemic. The national stockpile is the first line of defence. At the same time, the authorities should begin forecasting demand and check whether the backup capacity of the domestic supply chains can handle the predicted surge in demand. If not, the standby capabilities should be deployed, thereby

18. According to WHO (2018), it was estimated that disposed (medical) masks generate 1.6 million tons of plastic waste on a daily basis.

converting already developed capabilities into the capacity to produce the required amounts of critical products.

Conclusion

In recent years, there was insufficient realisation that the world had escaped narrowly from the SARS, MERS, Ebola, H1N1, and Zika epidemics.¹⁹ On top of that, the likelihood of even more severe pandemics is increasing in the future with the growing world population, more encounters between humans and wildlife, and widespread human interactions.

It is, therefore, critical that governments combine different approaches to become more responsive and resilient when facing future pandemics. We have outlined six such approaches following the United States' experience with PPE shortages reflecting poor preparedness. No country can afford to be complacent about future pandemics that must be surely lurking around the corner.

19. Their reasons are simple: 'the presence of a large reservoir of SARS-CoV-like viruses in horseshoe bats, together with the culture of eating exotic mammals in southern China, is a time bomb.'