STUDY

Ensuring Market Supply Transparency for Personal Protective Equipments

Preparing for Future Pandemics

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Abstract

The COVID-19 pandemic has exposed the opacity of the global personal protective equipment (PPE) supply chain. Dependence on international markets for medical PPE provision has left states vulnerable to price volatility and supply shortages. As the severity of the pandemic fluctuates amidst an ever-present risk of regional and global public health crises, medical PPE market volatility—exacerbated by the lack of accurate, up-to-date, transparent information of PPE international supply conditions—will continue to undermine effective policy responses and the resilience of healthcare systems around the world.

This article proposes a WTO/WHO joint initiative to ensure PPE market supply transparency for future pandemic preparedness. It departs from an analysis of the global PPE market, the impact of COVID-19 on PPE production and supply, and the systemic lack of basic PPE supply chain information at all levels. From this, it identifies the need for PPE market supply transparency and thus proposes creating a PPE market supply transparency system at the domestic and/or international level as a viable solution to enhance transparency and cooperation to better fight the next pandemic.

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Abbreviations

AMIS	Agricultural Market Information System
CHUV	Lausanne University Hospital
EPFL	École Polytechnique Fédérale de Lausanne
EU	The European Union
FDA	US Food and Drug Administration
IC	EPFL's School of Computer and Communication Sciences
IMF	International Monetary Fund
ITC	International Trade Centre
JMS	Joint Ministerial Statement
LDCs	Least Developed Countries
MSTS	Market Supply Transparency System
POSEIDON	Privacy-Preserving Federated Neural Network Learning
PPE	Personal Protective Equipment
PSCN	Pandemic Supply Chain Network
SARS	Severe Acute Respiratory Syndrome
SPU	Storage and Processing Unit
TFA	Trade Facilitation Agreement
UK	United Kingdom
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
US	The United States of America
WCO	World Customs Organization
WEF	World Economic Forum
WFP	World Food Programme
WHO	World Health Organization
WTO	World Trade Organization

SECTION 1

Introduction

The COVID-19 pandemic has exposed the opacity of the global market supply conditions of personal protective equipment (PPE). Dependence on international markets for medical PPE provision has left many states vulnerable to international price volatility and supply shortages. In the initial stages of the COVID-19 crisis, supply disruptions in China, the largest PPE producer, created a global shortage which led to panic buying, public and private hoarding, bidding wars, and hasty uncoordinated policy responses such as export bans. These aggravated the supply deficit and led to severe price inflation—the price of N95 masks increased up to 1300%[1]— and thus significantly undermined public health responses, particularly in developing countries. With the pandemic having revealed the integral role of trade in dealing with global crises, recovery measures and preparations for future crises must include measures to enhance the resilience of the global PPE supply chain.

To this end, the WTO recently published a paper titled 'Improving Trade Data for Products Essential to Fight COVID-19: A Possible Way Forward'. The paper argues that enhancing supply chain transparency through data sharing is a global public good and thus provides the following recommendation:

> "To the extent possible, launch and facilitate public-private partnerships with relevant stakeholders in order to collect as much trade-related information as possible from multiple sources. This is particularly important for gathering production data and mapping supply chains for essential goods. For products that are manufactured by relatively few producers, and provided that adequate guarantees can be provided by governments in terms of confidentiality and other considerations, try to establish a mechanism by which private companies can voluntarily share relevant information."[2]

Drawing from lessons learnt during the pandemic, this paper serves as a direct response to the WTO's recommendation and thus proposes the creation of a global market supply transparency system for PPE. While PPE is not the only essential good needed to fight pandemics, we believe that restricting the scope of this paper's proposal to PPE may serve as a politically viable pilot initiative, which may be broadened to cover a wider variety of essential goods and services in the future.

In making this proposal, the paper proceeds in four parts. Part 1 provides an introductory overview of the impact of COVID-19 on PPE supply to international markets, particularly through the imposition of export bans. Part 2 outlines key facts and figures about the global PPE market in the context of COVID-19, focusing on production, trade, and price. Part 3 discusses the dearth of information on PPE production and its consequences for policy

1 Nadia Garcia-Santaolalla, 'Obstáculos que Enfrentan los Países Actualmente para Proveer al Sector Salud y a la Sociedad en General de Insumos Médicos Esenciales para Hacer Frente a la Pandemia' (Tecnológico de Monterrey: Investigación de COVID-19 en México, 2020) <https://mexicovid19.app/> accessed 26 July 2020.

2 WTO, 'Improving Trade Data for Products Essential to Fight COVID-19: A Possible Way Forward' (2021) <https://www.wto.org/english/tratop_e/covid19_e/trade_data_report_e.pdf>.

responses throughout the pandemic. Part 4 analyses lessons learned from lack of supply-side information and examines two past approaches to enhance supply transparency: the Agricultural Market Information System and the Pandemic Supply Chain Network. Finally, part 5 recommends a WTO/WHO joint initiative to create a market supply transparency mechanism for PPE supply.

As the severity of the pandemic fluctuates amidst an ever-present risk of regional and global public health crises, PPE market volatility— exacerbated by the lack of accurate, up-to-date, transparent information on the availability of PPE to international markets— will continue to undermine the resilience of healthcare systems in both developed and developing countries. Therefore, it is the hope of the authors that this paper may kickstart a policy process for future pandemic preparedness and thus ultimately save lives when the next pandemic inevitably arises.

1.1 Defining PPE

Before analysing the impact of COVID-19 on the supply of PPE to international markets it is essential first to define those products classified as PPE. PPE refers to worn garments or equipment which minimizes exposure to hazards, such as pathogens. Broadly speaking this may include items such as gloves, face masks, safety glasses, shoes, earplugs or earmuffs, respirators, and vests. However different countries have a different understanding as to what exactly constitutes PPE due to a lack of internationally defined standards or definitions. For example, Chinese KN95 masks are not considered PPE in the US but have been approved as PPE in many other countries.[3]

This lack of consensus may even occur at the domestic level: according to the US Food and Drug Administration (FDA), PPE refers to protective clothing, helmets, gloves, face shields, goggles, face-masks and/or respirators or other equipment designed to protect the wearer from injury or the spread of infection or illness. [4] In contrast, the US Department of Labor considers PPE as the equipment used to minimize exposure to hazards that cause serious workplace injuries and illnesses.[5] Therefore, within the US, PPE may be considered both a medical device and an industrial protection garment not approved for medical use.[6]

While definitional disparity exists between countries, the WHO and WCO have provided guidance as to what should be considered PPE in the context of battling COVID-19. This includes face masks and respirators, protective spectacles and goggles, plastic face shields, gloves, hair nets, surgical gowns, and other protective garments.[7] For the purposes of this paper, we adopt this joint WHO and WCO definition of PPE, which includes those items encompassed in the third edition of the HS classification reference list for COVID-19 medical supplies (Appendix A). Moreover, to

3 Michael H Cecire and others, 'COVID-19 and Domestic PPE Production and Distribution: Issues and Policy Options' [2020] Congressional Research Service 71.
4 Center for Devices and Radiological Health, 'Personal Protective Equipment for Infection Control' (FDA, 11–38 May 2020) <https://www.fda.gov/medical-devices/general-hospital-devices-and-supplies/personal-protective-equipment-infection-control> accessed 23 August 2021.
5OSHA, 'Personal Protective Equipment - Overview | Occupational Safety and Health Administration' <https://www.osha.gov/personal-protective-equipment> accessed 23 August 2021.
6 WHO, 'Technical Specifications of Personal Protective Equipment for COVID-19' <https://www.who.int/publications-detail-redirect/WHO-2019-nCoV-PPE_specifications-2020.1> accessed 17 August 2021.
7 WCO, 'HS Classification Reference for Covid-19 Medical Supplies 3.01 Edition' <http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/nomenclature/covid_19/hs-classification-reference_edition-3_en.pdf?la=en> accessed 17 September 2021.

streamline our analysis, and given their overwhelming share of the PPE category, this paper will focus on the production, trade, and use of masks, gloves, goggles, and protective garments.

1.2 Impact of COVID-19 on PPE Market Supply

The COVID-19 pandemic has caused an unprecedented increase in demand for medical supplies and services with countries scrambling to source PPE, medicines, medical devices and equipment, and other related goods in a context of disrupted global supply chains. [8] Exponential growth in domestic demand for PPE in the first half of 2020 prompted most PPE producing nations to implement export bans. The most significant restrictions in terms of impact on the global supply of PPE were those implemented by the US, EU, and China, given the dominance of these actors in the global PPE market. First, the US implemented a ban on the export of PPE in April 2020, with special exemptions for exports to US humanitarian missions, Canada, and Mexico. This is estimated to have affected $1.1 billion of US exports. [9] Second, in March 2020, many European countries unilaterally implemented bans on the intra and extra-EU export of PPE—in defiance of the principles of the common market. The European Commission quickly dissolved restrictions on intra-EU PPE exports but implemented an exceptionally restrictive EU-wide PPE export licensing scheme which effectively amounted to an export ban.[10] Last, in early February 2020, China nationalized control over the domestic production and distribution of PPE, diverting export-bound PPE to meet domestic demand through procurement measures. This was followed by the imposition of new export licensing requirements in April 2020, under which all exports needed to be approved by the National Medical Products Association. While this was reportedly done to ensure the quality of exported PPE, some analysts contend it restricted PPE exports and allowed the Chinese government to orchestrate selective PPE deliveries to specific countries for political gain.[11]

By June 2020, a total of 47 countries had notified the WTO of restrictions on PPE exports, including Argentina, India, South Africa, Ukraine, Australia, and Thailand. However, the number of de facto export restrictions are likely to be much higher given the poor state of notifications at the WTO.[12] In the short run, export restrictions increase domestic supply and reduce domestic prices but may lead to shortages in international markets and inflated international prices. Additionally, export restrictions may prompt a knock-on effect of inducing other countries to implement their own export restrictions, which exacerbates these shortages. [13] The

8 Emma Mcevoy and Delia Ferri, 'The Role of the Joint Procurement Agreement during the COVID-19 Pandemic: Assessing Its Usefulness and Discussing Its Potential to Support a European Health Union' (2020) 11 European Journal of Risk Regulation 851.
9 Christopher A Casey and Cathleen D Cimino-Isaacs, 'Export Restrictions in Response to the COVID-19 Pandemic' [2021] Congressional Research Service 3.
10 BDI, 'Export Controls and Export Bans over the Course of the COVID-19 Pandemic' (2020) <https://www.wto.org/english/tratop_e/covid19_e/bdi_covid19_e.pdf>.
11 Michael Cecire, 'COVID-19 and Domestic PPE Production and Distribution: Issues and Policy Options' (Congressional Research Service, 2020) <https://crsreports.congress.gov/product/pdf/R/R46628>.
12 Jiangyuan Fu, Joseph A McMahon and Huidan Xue, 'More Restriction or Facilitation on PPE amid COVID-19: Limitations and Options of International Trade Law' (2020).
13 CRS, 'Export Restrictions in Response to the COVID-19 Pandemic' (2021) <https://crsreports.congress.gov/product/pdf/IF/IF11551>.

IMF and WTO clearly illustrate this point in the following statement:

> "Taken collectively, export restrictions can be dangerously counterproductive. What makes sense in an isolated emergency can be severely damaging in a global crisis. Such measures disrupt supply chains, depress production, and misdirect scarce, critical products and workers away from where they are most needed. Other governments counter with their own restrictions. The result is to prolong and exacerbate the health and economic crisis — with the most serious effects likely on the poorer and more vulnerable countries."[14]

Consequently, the domino effect of export restrictions which unfolded in 2020 created substantial uncertainty and volatility in the international PPE market and was incredibly counterproductive given that almost all countries are net-importers of PPE. The globalized nature of the PPE supply chain and the harmful impact of PPE export restrictions will be explored in more detail in the following section.

14 ibid.

SECTION 2

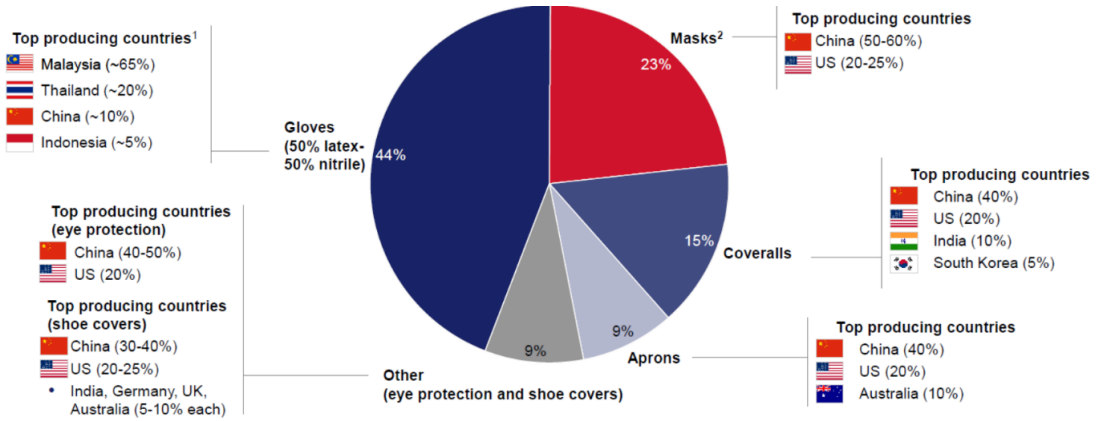
PPE Production and Trade: Key Facts and Figures

2.1 Production

Making an accurate assessment of global PPE production is challenging for two reasons. First, as mentioned in Part, 1 there is a lack of consensus on what products constitute PPE as differing classification schemes include and exclude different products. Second, and more crucially, manufacturers do not share PPE production data such as quantity, location, and stock. This unavailability of production data means that policymakers and consumers do not know where their domestic PPE supply is produced and by whom. Thus, to provide a rough impression of global PPE production trends, this section substitutes the lack of concrete data with estimates from different sources to create as complete a picture of global PPE production as possible.

China is the world's largest producer of PPE and produced 40-60% of global PPE prior to COVID-19.[15] After the pandemic broke, China rapidly increased PPE production, with the daily output of protective gowns and N95 masks increasing by 1200% and 800%, respectively. [16] These production increases meant China supplied as much as 83% of PPE to global markets in May 2020[17] and around 80% in 2020 overall.[18]

Figure 1: PPE Production Market Share (2019)



Source: IFC 2020

15 IFC, 'Covid-19 PPE Demand and Supply Perspectives' (2020) <https://www.ifc.org/wps/wcm/connect/1d32e536-76cc-4023-9430-1333d6b92cc6/210302_FCDO_GlobalPPE_Final+report_v13_gja.pdf?MOD=AJPERES&CVID=nvPXlAZ> accessed 23 August 2021.

16 Chad P Bown, '21-11 How COVID-19 Medical Supply Shortages Led to Extraordinary Trade and Industrial Policy' 30.

17 Taisei Hoyama and Rintaro Hosokawa, 'Reliance on Chinese Protective Gear Soars in Pandemic's Wake - Nikkei Asia' <https://asia.nikkei.com/Spotlight/Coronavirus/Reliance-on-Chinese-protective-gear-soars-in-pandemic-s-wake> accessed 23 August 2021.

18 Daniel Joseph Finkenstadt and Robert Handfield, 'Blurry Vision: Supply Chain Visibility for Personal Protective Equipment during COVID-19' (2021) 27 Journal of Purchasing and Supply Management 100689.

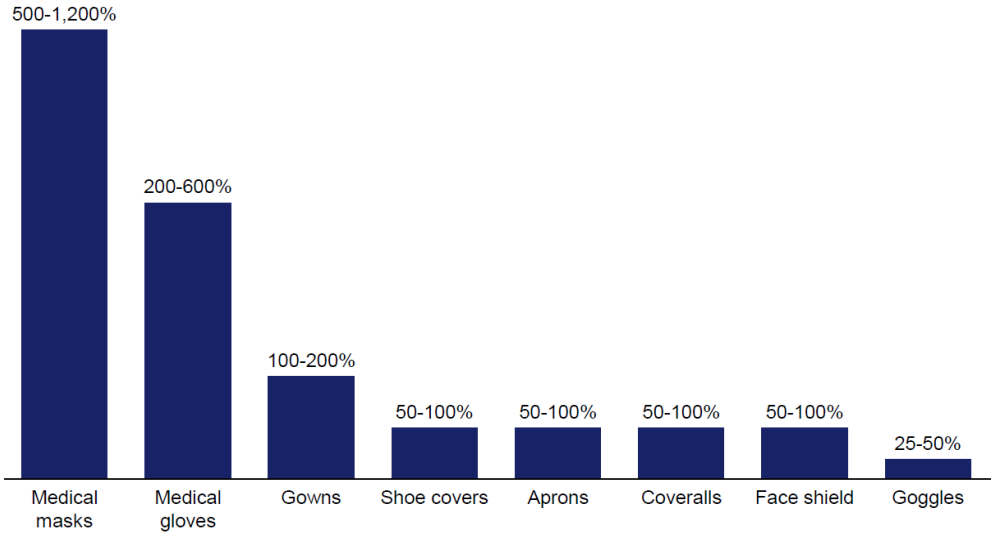
Prior to the pandemic the US was the second-largest producer, with a production of 20-25% of global PPE. The US hosts the headquarters of some of the largest PPE companies, including 3M, Honeywell, and Kimberly Clark, but it is unclear what proportion of their PPE is produced domestically. However, with the onset of the pandemic, India is reported to have increased PPE production by 5600% in the span of 2-3 months to meet domestic demand, and thus replaced the US as the second-largest producer of PPE in the world. Having said this, given the size of India's population, the vast majority of domestic PPE production is consumed locally, which makes India a minor supplier to international markets.[19]

Several other countries also rapidly increased production with the onset of the pandemic. Chinese Taipei increased mask production to 15 million masks per day, positioning it as the second-largest producer of masks. [20] Bangladesh and Vietnam increased production of PPE by 1000% and 600%, respectively. These rapid production increases can be attributed to the strong textile manufacturing bases in these countries, as over 50% of increased production came from textile manufacturer who switched production lines to PPE to take advantage of increased global prices and offset drops in demand for textiles. While stabilizing PPE prices will incentivize these manufacturers to revert to textiles, these countries have an opportunity to increase their share of global PPE production, given their competitive advantage in the sector.[21]

Notwithstanding the foregoing, PPE production is incredibly concentrated in a few countries with low production costs. The largest PPE firms are headquartered in the US but outsource production to China, where labour costs for manufacturing are $5.72 per hour compared to $23.71 per hour in the US[22], and the availability of supply linkages and high production capacity help drive costs even lower. While demand spikes and supply shortages incentivized investment in local PPE manufacturing capacity in many countries, the low longevity of demand has forced many of these producers to subsequently shut down due to their inability to compete with cheaper Chinese imports.[23] Additionally, this perceived low longevity of demand and correlative investment risk dissuaded investors even during periods of excess demand—meaning many countries did not increase local manufacturing capacity and continue to depend on imports of PPE throughout the pandemic.[24]

19 IFC (n 15).
20 Tinglong Dai, Ge Bai and Gerard F Anderson, 'PPE Supply Chain Needs Data Transparency and Stress Testing' (2020) 35 Journal of General Internal Medicine 2748.
21 IFC (n 15).
22 Trading Economics, '20 Million Indicators from 196 Countries' <https://tradingeconomics.com/> accessed 23 August 2021.
23 Monika Evstatieva, 'U.S. Companies Shifted To Make N95 Respirators During COVID. Now, They're Struggling' (NPR.org) <https://www.npr.org/2021/06/25/1009858893/u-s-companies-shifted-to-make-n95-respirators-during-covid-now-theyre-struggling> accessed 23 August 2021.
24 Samantha DeCarlo, 'COVID-19 Related Goods: The U.S. Industry, Market, Trade, and Supply Chain Challenges' 4.

Figure 2: Estimated Peak Increases in Global PPE Production in 2020



Source: IFC 2020

Overall, while global PPE production skyrocketed in 2020 (Figure 2), it has further concentrated in China and Southeast Asia. Therefore, rather than diversifying and reshoring PPE supply chains, the pandemic may entrench global dependence on imports for PPE. The dynamics of PPE trade will be explored in the next section.

2.2 Trade

Unsurprisingly, overall trade in PPE surged in 2020, increasing by 433% from $20.9 billion in 2019 to $90.5 billion in 2020. Exports primarily consisted of masks (Figure 3) worth $69.1 billion in 2020, a 466% increase in value from 2019. The largest exporter of masks is China, accounting for 77% of total exports, followed by Germany, with a relatively meagre market share of 2.75% of total mask exports. The largest importers of masks are the US (25.2% of total imports), followed by Germany (10.3%) and France (8.9%), with 82-85% of masks imported by these countries coming from China.[25]

Medical gowns are the second most traded type of PPE, worth $14.8 billion in 2020, having grown 599% compared to 2019. Again, the largest exporter of medical gowns is China which accounted for 74.2% of total exports in 2020, followed by Turkey (6%) and Vietnam (4.23%), while the largest importers were the US (27.8%), the UK (16.2%), and Germany (4.7%). These importers relied on China for 72-85% of their import of gowns.[26]

The third most traded PPE product is medical goggles and face coverings, worth $3.8 billion in 2020 and having grown 11% compared to 2019. The largest exporter was China which contributed 49.1% to total exports, followed by Chinese Taipei (10.1%) and Germany (5.4%). The largest importer was the US

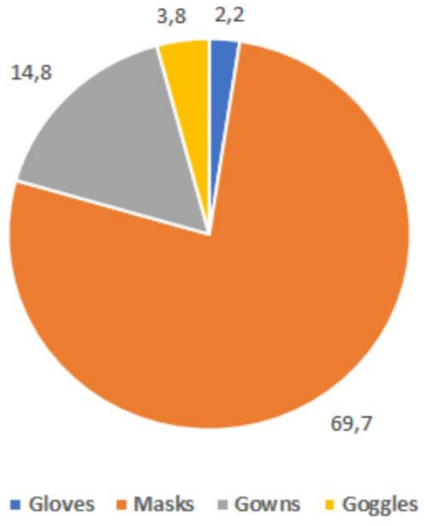
25 ITC, 'Trade Map - Trade Statistics for International Business Development' <https://www.trademap.org/Index.aspx> accessed 23 August 2021.

26 ibid.

which accounted for 24.5% of total imports, followed by the UK (16.2%) and Australia (6.3%). China accounted for 60-85% of these countries' imports of medical goggles.[27]

Last, exports of surgical gloves were worth $2.2 billion in 2020, a 51% increase from 2019. Interestingly, export-oriented production of surgical gloves seems highly diversified relative to other PPE products, as although China is still the largest exporter, it only accounts for 20.9% of the market, followed by Malaysia (19.4%) and Germany (14.1%). The largest importers are Germany (19.2%), the UK (14.9%), and the US (11.1%), with imports sourced equally from Malaysia, Thailand, and China.[28]

Figure 3: Composition of Global PPE Exports in 2020 ($Billion)



Source: (ITC 2021) and authors own calculations.[29]

As this section shows, China is incredibly dominant in the global PPE market, with much of the world reliant on China for imports of PPE—China is the primary supplier for nine of the top 10 PPE importers.[30] It is important to note, however, that while trade statistics confirm China's monopolistic role in international markets, they do not paint a complete picture of global PPE consumption and production patterns. Trade statistics do not reveal the location or quantity of PPE produced for domestic consumption, nor what percentage of a country's domestic demand is met through domestic production, e.g., the degree of dependence a country has on imports to meet domestic PPE demand. Although these questions are crucial for policymakers to assess domestic PPE supply vulnerability, they have no answers given the lack of PPE supply transparency.

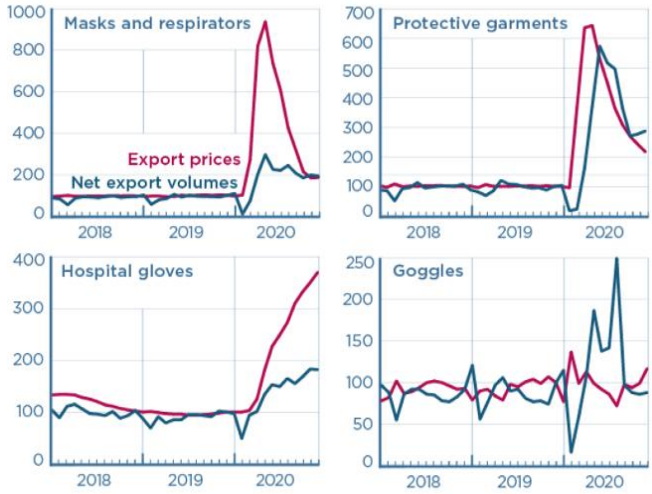
2.3 Price

In 2020 the prices of PPE on global markets skyrocketed due to a perfect storm of concentrated production, restrictions on supply, and soaring demand. The rapid increase in demand for PPE during the first few months of 2020 is well known since healthcare systems required huge quantities of PPE as they bore the brunt of COVID-19. Overall, demand increased by 300-400% in 2020 relative to 2019, mainly driven by increased consumption of surgical masks due to government mask mandates in many countries—with masks constituting 40% of PPE demand in 2020 compared to 5% in 2019.[31]

27 ibid.
28 ibid.
29 HS codes used to calculate each category may include a wider array of goods other than PPE. However these codes are used by the WTO to calculate trade in PPE. These include HS630790 (masks), HS401511 (gloves), HS621010 (gowns) and HS900490 (goggles).
30 WTO, 'Trade in Medical Goods in the Context of Tackling COVID-19' (2020) <https://www.wto.org/english/news_e/news20_e/rese_03apr20_e.pdf> accessed 23 August 2021.
31 IFC (n 15).

Soaring demand was exacerbated by constrictions on supply as restrictions on worker movement, labour shortages, and disruption to the supply of inputs all prevented PPE manufacturers from increasing production.[32] PPE trade was also severely disrupted, as border closures and the grounding of air freight caused transport costs to rapidly increase, with several PPE traders reporting paying $2.50 in shipping costs per mask in April 2020 compared to $0.35 per mask prior to the pandemic.[33] Dependence on China for PPE rendered supply vulnerable to Chinese domestic shocks: as COVID-19 continued to worsen in China in Q1 of 2020, production was shifted away from meeting international demand towards supplying the domestic market—mainly through export restrictions, as discussed in Part 1. A combination of these factors caused international PPE prices to spike by 400% on average.[34] Once China resumed PPE exports, it was reportedly charging over 700% more for masks, 650% more for medical gowns, and 400% more for gloves.[35] These high prices were accompanied by severe backlogs, with PPE orders taking as much as 4-6 months to be fulfilled during the height of the pandemic (Figure 4).

Figure 4: China's monthly PPE export volumes and prices ($ per kg)



Source: Brown 2021

Global demand for PPE is expected to subside throughout 2021 and 2022 as increasing vaccination rates reduce pressure on healthcare systems. However, demand is projected to remain substantially higher than pre-pandemic levels as COVID-19 persists in many parts of the world, non-medical consumers remain sensitized to the need to wear masks, and workers return to non-medical employment which requires PPE.[36]

32 Priyabrata Chowdhury and others, 'COVID-19 Pandemic Related Supply Chain Studies: A Systematic Review' (2021) 148 Transportation Research Part E: Logistics and Transportation Review 102271.
33 DeCarlo (n 24).
34 Asian Development Bank and others, 'Global Shortage of Personal Protective Equipment amid COVID-19: Supply Chains, Bottlenecks, and Policy Implications' (Asian Development Bank 2020) <https://www.adb.org/publications/shortage-ppe-covid-19-supply-chains-bottlenecks-policy> accessed 23 August 2021.
35 Bown (n 16).
36 IFC (n 15).

SECTION 3

The Dearth of Information on PPE Supply and its Impact

3.1 International Markets

PPE shortages have exposed the hyper-globalized nature of the PPE supply chain described in the previous section and revealed the vulnerability of PPE supply to changes in national politics. This vulnerability ultimately stems from individual optimization decisions by firms, which have resulted in a severe lack of systemic diversification needed to ensure supply resilience and made markets more vulnerable to supply shocks. The following passage by Talha Burki illustrates the point:

> "Worldwide supply chain networks have been a key feature of globalization from which multinational corporations seeking low-cost supplies have benefited mostly. Offshoring, lean manufacturing, and just-in-time inventory—proven measures to cut costs—may have stretched the global supply chain to a breaking point in times of stress. These business practices now make the companies extremely vulnerable to disruptions in parts of the supply chain or where trade restrictions are in place."[37]

While the vulnerability of supply of strategic goods such as PPE is clearly problematic, policymakers were not aware of this issue until recently given the lack of basic information on PPE supply. This lack of information also complicates policy choices, as policymakers make underinformed decisions and may implement hasty and uncoordinated measures which exacerbate market volatility, such as export bans.[38] Moreover, a lack of PPE supply information increases uncertainty among consumers, which encourages those with the means to panic buy and stockpile PPE, as occurred in 2020. This further exacerbated the supply deficit, artificially increased prices, and prevented poorer countries from acquiring much-needed PPE. Ultimately the lack of market information helped transform PPE markets into "the Wild West"[39] in 2020, with accusations of modern-day piracy abounding as countries scrambled to source PPE in any way they could.[40]

[37] Talha Burki, 'Global Shortage of Personal Protective Equipment' (2020) 20 The Lancet Infectious Diseases 785.
[38] AMIS, 'Enhancing Market Transparency' (2011) <http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/reports/Improving_global_governance_for_food_security.pdf> accessed 23 August 2021.
[39] Marieke Walsh and Nathan VanderKlippe, 'Ottawa and the Provinces Are Navigating a "Wild West" in the Medical Supply Market - The Globe and Mail' <https://www.theglobeandmail.com/politics/article-ottawa-and-the-provinces-are-navigating-a-wild-west-in-the-medical/> accessed 23 August 2021.
Marieke Walsh and Nathan VanderKlippe, 'Ottawa and the Provinces Are Navigating a "Wild West" in the Medical Supply Market' *The Globe and Mail* (Ottawa, Beijing, 2020) <https://www.theglobeandmail.com/politics/article-ottawa-and-the-provinces-are-navigating-a-wild-west-in-the-medical/> accessed 13 August 2021.
[40] Devon E McMahon and others, 'Global Resource Shortages during COVID-19: Bad News for Low-Income Countries' (2020) 14 PLOS Neglected Tropical Diseases e0008412.

3.2 Domestic Market Case Study: United States of America

The lack of information on PPE supply stems from the lack of production data at the domestic level, which makes it extremely difficult to discern the degree to which domestic PPE demand is met through local manufacturing or imports.[41] This may cause policymakers to exacerbate shortages at a domestic level too: for example, US tariffs on Chinese PPE imports increased prices by up to 25%, yet while US demand for PPE quadrupled by February 2020, these tariffs were only lifted in March. [42] A study conducted on the US PPE supply chain in 2020—which examined five years of financial reports by the largest producers and conducted an exhaustive search of over 1700 media reports on PPE supply published in Q1 of 2020—could not find even basic supply chain data such as the overall quantity of N95 masks produced in the US.[43]

US policymakers identified the opacity of PPE supply as a significant hindrance to COVID-19 response measures and thus commissioned an inquiry into the US domestic PPE market. [44] This increased scrutiny and relative availability of information make the US a helpful case study into the opacity of domestic PPE markets, while its dependence on Chinese imports makes it representative of most countries.

The congressional report estimated that the US relies on imports for 80-90% of its PPE supply, 75% of which comes from China. This makes the US the largest importer of PPE globally, with little pre-pandemic PPE production being sold to the domestic market.[45] Therefore, domestic production was grossly insufficient to meet surging demand at the onset of the pandemic: for example, the US required 1.8 billion gloves a week but was only producing 500 million gloves annually.[46] At the same time, 40% of medical facilities were unable to obtain N95 masks in the first half of 2020[47] as 95% of N95 masks were imported from China[48]. Severe shortages led to delays of 3-6 months for urgently required PPE, forcing doctors and hospitals to resort to sourcing PPE through personal networks. [49] Many were forced to purchase PPE through unvetted sources without the ability to evaluate quality, leading to a surge in counterfeit products and substantial losses for desperate healthcare providers.[50]

The opacity of the PPE supply chain enabled the production and sale of counterfeit PPE to flourish, with over 12.7 million counterfeit N95 masks seized in the US in 2020 alone.[51] To try and overcome the shortfall, the US government deployed a total of $1.2 billion in subsidies in 2020 to scale up domestic PPE production. However, due to a lack of information on domestic PPE production, the deployment of subsidies was delayed as policymakers struggled to determine where they should be targeted and what sums were appropriate. [52] The congressional report concluded that a lack of production data

[41] Bown (n 16).
[42] DeCarlo (n 24).
[43] Dai, Bai and Anderson (n 20).
[44] DeCarlo (n 24).
[45] ibid.
[46] Bown (n 16).
[47] Finkenstadt and Handfield (n 18).
[48] DeCarlo (n 24).
[49] Preeti Mehrotra, Preeti Malani and Prashant Yadav, 'Personal Protective Equipment Shortages During COVID-19—Supply Chain–Related Causes and Mitigation Strategies' (2020) 1 JAMA Health Forum e200553.
[50] DeCarlo (n 24).
[51] ibid.
[52] Bown (n 16).

severely hindered effective policy responses, noting that its own findings were reliant upon production data from 2017[53]. As Chad P. Bown writes, "To better support policy going forward, the United States must collect and maintain up-to-date, detailed data on domestic production and capacity for PPE."[54]

3.3 Additional Impact on Developing and Least Developed Countries

The challenges faced by the US are shared by and particularly acute for developing and least developed countries (LDCs), which have fewer resources and less resilient healthcare systems—the average low-income country has 0.2 physicians and one nurse per 1,000 people, compared to 3 physicians and 8.8 nurses in high-income countries.[55] Moreover, their even greater reliance on international markets forced developing countries and LDCs to bid against wealthy countries for limited PPE supplies in 2020, competing according to means and not needs.[56] This led to severe shortages of PPE in developing countries and LDCs, and undermined their limited capacity to deal with COVID-19 as already scarce healthcare workers increasingly became infected and incapacitated.[57]

LDCs were particularly affected, as many are heavily indebted and cannot finance the import of PPE even in times of market stability let alone when prices were artificially inflated in 2020. This meant that despite LDCs containing 13.3% of the global population, they only accounted for 1% of COVID-19 related goods imports[58] which exacerbated pre-existing shortages (Figure 5). Both Asian and African LDCs were subject to PPE supply shortages. Asian LDCs import most of their PPE from China,[59] while African LDCs mainly import PPE from South Africa and India, all of which implemented PPE export bans in 2020.[60] While this again demonstrates the interconnected and vulnerable nature of the international PPE supply chain, it is unrealistic to expect LDCs to develop domestic manufacturing capacity given low levels of human and physical capital. Instead, global coordination of demand and diversification of supply facilitated by supply-side transparency is needed to ensure that LDC PPE needs are met.

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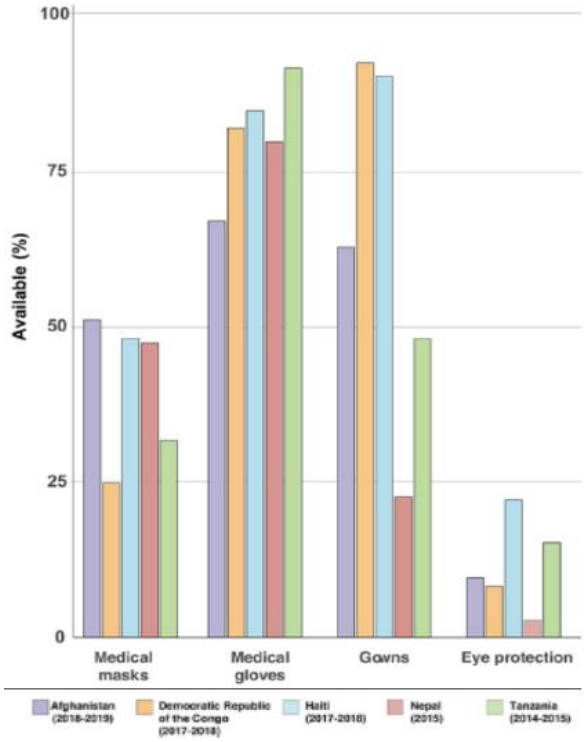
[53] DeCarlo (n 24).
[54] Bown (n 16).
[55] 'Health Systems in Low-Income Countries Will Struggle to Protect Health Workers from COVID-19' (*Center For Global Development*) <https://www.cgdev.org/blog/health-systems-low-income-countries-will-struggle-protect-health-workers-covid-19> accessed 23 August 2021.
[56] Tinglong Dai and others, 'Supply Chain Failures amid Covid-19 Signal a New Pillar for Global Health Preparedness' (2021) 30 Journal of Clinical Nursing <https://onlinelibrary.wiley.com/doi/10.1111/jocn.15400> accessed 23 August 2021.
[57] EIF, 'Unpacking COVID-19-Related Medical Supply Chains in Commonwealth LDCs' (*Trade 4 Dev News*, 14 July 2020) <https://trade4devnews.enhancedif.org/en/op-ed/unpacking-covid-19-related-medical-supply-chains-commonwealth-ldcs> accessed 23 August 2021.
[58] ibid.
[59] ITC (n 25).
[60] EIF (n 57).

Figure 5: Availability of PPE for Select LDCs



Source: McMahon et al., 2020

SECTION 4

Lessons Learned

4.1 The Imperative Need for PPE Market Supply Transparency

Publicly available information on global PPE supply can be considered a market-enhancing mechanism and global public good to the benefit of both consumers and producers. Supply-side information shapes expectations and future prices and ensures that all economic actors make informed and efficient decisions.[61] The Asian Development Bank concurs, arguing the following:

> "Transparent and comprehensive information about availability of products on the market, production capacity, and supply response is critical for PPE readiness during these outbreaks, epidemics, and even more so for pandemics… Sharing information and communicating regularly. An efficient, low-burden mechanism for governments and private sector partners to share situational and supply information needs to be developed."[62]

Creating such a system would facilitate a cooperative and coordinated response between countries based on transparency and would likely do much to calm international market volatility and prevent knee-jerk export restrictions in the future.[63] Preventing future volatility would reduce instances of panic buying and hoarding, thereby ensuring price stability which is ultimately to the benefit of consumers.[64] Market supply transparency would also benefit manufacturers by informing their investment and production decisions, allowing them to coordinate supply chains, and manage logistics more efficiently.[65] For policymakers, it would permit better informed and coordinated decision-making at both domestic and international levels and help ensure improved supply chain readiness and resilience in meeting future demand surges. Reliable supply data would help inform policy decisions to scale up PPE production more accurately, set price expectations for PPE acquisition and bidding from states, and enable the targeted and appropriate deployment of state resources.[66]

4.2 Past Initiatives to Collect Market Supply Data During a Crisis

In recognition of the value of transparency in supply chains, two key initiatives have been launched in the past to collect, aggregate, and disseminate supply-side information to prevent market volatility in times of crisis. First, the Agricultural Market Information System (AMIS) was created in response to the 2007-2008 global food crisis during which unexpected price hikes on foodstuffs led to export bans, hoarding and widespread food insecurity. In addressing the crisis, ten international organizations (including the

[61] AMIS (n 38).
[62] Asian Development Bank and others (n 34).
[63] Bown (n 16).
[64] AMIS (n 38).
[65] Chowdhury and others (n 32).
[66] Shuhan He and others, 'Effective Supply Chain Surveillance for PPE' (2021) 397 The Lancet 1706.

WTO) and other actors identified as primary causes the lack of supply-side information on crop supply and export availability, as well as general insufficient market transparency throughout the global agri-food supply chain [67]. This problem was addressed by creating the AMIS: a global policy coordination platform with access to up-to-date data on global crop supplies to improve agricultural market and policy information, analysis, and short-term supply forecasts at national and international levels.[68] Since its creation, it has enhanced transparency and policy coordination in international food markets which has helped prevent price spikes and strengthen global food security.[69]

Second, the Pandemic Supply Chain Network (PSCN) was created by the World Economic Forum (WEF) in 2015[70] in response to supply chain failures during the 2014 West African Ebola epidemic— particularly the limited information on the overall supply and demand of critical health products and a lack of private sector coordination. [71] The PSCN brought together the private sector and global organizations such as the WHO, WEF, the World Bank, UNICEF, the WFP, and other global partners to develop a transparency framework for pandemic preparedness and response by encouraging partners to share information on pandemic supplies and logistics.[72]

In the context of COVID-19, the PSCN has been described as "an informal group of public-private partnership activities that relate to moving of or obtaining information on where PPE is manufactured, where it is available, what supply chain capabilities exist, what logistics exist, and figuring a way to deal with these issues of shortages". [73] Henry Shein Inc., a co-founder and the private sector lead of the PSCN, states that since its inception there has been intensive work to develop "a platform for data sharing, market visibility, and operational coordination for health care products to more effectively match global demand with global supply." [74] However, despite the existence of the PSCN since 2015, the world still suffered from a lack of PPE supply-side information during the COVID-19 pandemic. According to Stanley M. Bergman, Chairman of the Board and CEO of Henry Shein Inc., a lack of collaboration hinders the PSCN effectiveness because the PSCN is "not a government" but a "group of people".[75]

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[67] G20, 'Ministerial Declaration: Action Plan on Food Price Volatility and Agriculture' (2011) <http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/2011-agriculture-plan-en.pdf>.
[68] AMIS (n 38).
[69] AMIS, 'Agricultural Market Information System: About' (2021) <http://www.amis-outlook.org/amis-about/en/> accessed 22 August 2021.
[70] WEF, 'Pandemic Supply Chain Network (PSCN)' (*World Economic Forum*) <https://www.weforum.org/projects/pandemic-supply-chain-network-pscn/> accessed 19 August 2021.
[71] WFP, 'Innovative Supply Chain Information Platform Will Help Prepare For The Next Pandemic | World Food Programme' (2017) <https://www.wfp.org/news/innovative-supply-chain-information-platform-will-help-prepare-next-pandemic> accessed 22 August 2021.
[72] ibid.
[73] 'Vaccinating the World: From Mass Production to Last-Mile Delivery (Option 2) - English' <https://www.weforum.org/videos/davos-2021-vaccinating-the-world-from-mass-production-to-last-mile-delivery-option-2-english/> accessed 18 August 2021.
[74] 'Henry Schein Named to Fortune® Magazine's "Change the World" List | Henry Schein' <https://investor.henryschein.com/news-releases/news-release-details/henry-schein-named-fortuner-magazines-change-world-list> accessed 18 August 2021.
[75] 'Vaccinating the World: From Mass Production to Last-Mile Delivery (Option 2) - English' (n 73).

SECTION 5

A Way Forward

Drawing on lessons learnt from COVID-19, AMIS and the PSCN, this paper proposes the creation of a PPE Market Supply Transparency System (MSTS), which would leverage current cloud computing and encryption technologies to provide real-time information on PPE supply to policymakers and manufacturers.[76] This would allow them to gauge and forecast PPE markets at regional, national, or global levels and mirror the role that AMIS plays in ensuring stability in global agri-food markets and enhancing international policy dialogue.

To this end, we have identified two challenges to establish a system to collect PPE market supply data successfully. First, the need for governmental support to impel private and public companies to share private, sensitive information. Second, the need to soothe companies' concerns regarding the security of the information shared. To address these two challenges, we draw on insights obtained through an informal discussion with an AMIS participant and an École Polytechnique Fédérale de Lausanne (EPFL) information security expert.

5.1 The Market Supply Transparency System (MSTS)

Policy decisions to fight a health crisis should be based on timely and credible data on domestic and global PPE supplies and prices. However, even though over the last two decades the world has experienced a number of disease outbreaks, including the severe acute respiratory syndrome (SARS-CoV-1) in 2002-2003, the H1N1 pandemic influenza in 2009, the Ebola outbreak in West Africa in 2014-2016, the Middle East respiratory syndrome coronavirus (MERS-CoV) in 2012, [77] and the Coronavirus in 2019 (COVID-19), PPE manufacturers in most countries are currently not required to disclose basic PPE supply data such as manufacturing capacity, output, and available inventory.

As previously discussed, almost no country is self-sufficient in producing PPE, and supply data that allows economic actors to make informed decisions can be vital in ensuring the affordable and uninterrupted supply of PPE during crises. It bears to mention that reshoring PPE production will not make supply chains more resilient to future pandemic-type shocks. In fact, it will have the

[76] Nadia García-Santaolalla, 'A Proposal to Reform "Security-Emergency" Exceptions in Trade' (*ESCAP Online Repository of Contributions to the Policy Hackathon on Model Provisions for Trade in Times of Crisis and Pandemic*) 38 <https://www.unescap.org/resources/online-repository-contributions-policy-hackathon-model-provisions-trade-times-crisis-and> accessed 19 August 2021 (Subprinciple 7.1).

[77] David E Bloom and Daniel Cadarette, 'Infectious Disease Threats in the Twenty-First Century: Strengthening the Global Response' (2019) 10 Frontiers in Immunology 3 <https://www.frontiersin.org/article/10.3389/fimmu.2019.00549/full> accessed 23 August 2021.

opposite effect since participation in global supply chains alleviates vulnerability to pandemic-induced localised shocks. The intuition for this line of reasoning is simple: eliminating the dependence on foreign inputs increases the dependence on domestic inputs. Since any national pandemic-related lockdown also affects domestic manufacturers, there is generally no resilience benefit from reshoring PPE supply chains.[78]

On the other hand, overreliance on a small number of foreign suppliers proved inadequate during the pandemic. Thus, diversification of foreign sources would significantly enhance supply chain resilience. However, as exhibited in section 3.2, the lack of production data at the domestic level makes it extremely difficult to discern the degree to which domestic PPE markets have diversified supply from foreign sources. Consequently, the need for transparent market supply data, both at the domestic and international levels, remains imperative to tackle the next pandemic.

The reasons for insufficient supply data are multiple. At the domestic level, some countries may not have legislation that requires its collection; inventories can be very dispersed among manufacturers, distributors, traders, and other actors, and challenging to track; and some manufacturers may have data security concerns. At the international level, some countries may lack the capabilities to properly implement further trade-related commitments on information sharing due to a lack of infrastructure, technological capacities, or know-how. The lack of a legal framework to impel the private and public sectors to share PPE supply data affects countries' ability to fight a pandemic. In this vein, it is worth highlighting that in democratic countries, the cost of policymaking without adequate data can be losing office in the next elections. Considering this, the governments' buttress to incentivize firms to share PPE supply information is in their self-interest: better-informed and coordinated policy responses contribute to supply chain resilience and ensure adequate PPE readiness to safeguard peoples' lives, health, and livelihoods during a crisis.

To this end, the MSTS proposed in this paper constitutes a way to overcome market inefficiencies and distortions through a non-market-distorting measure by enabling the efficient allocation of PPE supply and capital. Nevertheless, as mentioned earlier, there are two critical challenges that this system needs to overcome to become viable (1) guarantee the security of data and (2) obtain governmental buttress to impel private and public companies to share bare minimum information on PPE supply.

5.2 Data Security

In the last few years, developments in cryptographic privacy-enhancing technologies have greatly reduced specific data security challenges. Multiparty homomorphic encryption brings together two of the most potent software-based privacy-enhancing technologies: homomorphic encryption and secure multiparty computation.

Homomorphic encryption is a form of encryption that allows computations to be performed on encrypted data without the need for decryption. Current practical schemes using homomorphic encryption have reached

[78] See Simon J. Evenett in 'Live Session 1-Pilot Course on Negotiating Regional Trade Agreements for Trade in Times of Crisis and Pandemics' <https://www.youtube.com/watch?v=SAgPfCC0O1o&list=PLgTVHD_RzYIMjVS6xrDxg6g8XLpkbco3t&index=11> accessed 19 August 2021.

a level of maturity that enable their use in real-world scenarios. Such schemes permit the computation of polynomial operations—including addition, subtraction, and multiplication—on encrypted data.[79] As a result, homomorphically encrypted data can be securely delivered to third parties, who can perform meaningful operations on it without knowing anything about its contents. In short, this means that a third party can process data without being able to "see it".[80] Homomorphic encryption is therefore helpful to aggregate PPE supply data without raising security concerns for manufacturers.

On the other hand, secure multiparty computation is a cryptographic protocol that enables multiple parties to jointly compute functions over their private inputs with no individual party able to see the other parties' data.[81] This means that when there are multiple parties involved (e.g., PPE manufacturers, distributors, or governments), it is possible to let the computations take place without centralizing the data. During the computations, there is a "kind of exchange" of information around them but without sending the data—this means that the algorithm goes to the data and not the other way around—and in the end, each party can only access the aggregated output.[82]

Both secure multiparty computation and homomorphic encryption are complementary encryption techniques that rely upon mathematically proven guarantees for data confidentiality.[83] Secure multiparty computation makes it possible to confidentially analyse PPE data from different parties without any party accessing each other's information, except for the final aggregated result (Figure 6). When paired with homomorphic encryption, which allows computations to be performed on encrypted data without decrypting it, the data remains protected end-to-end from both internal and external attacks.[84] The ability to carry out computations on data without moving or decrypting it is crucial to the successful operation of the MSTS.[85] Multiparty homomorphic encryption thus makes it possible to confidentially analyse data at different manufacturers', distributors', or governments' sites,[86] which provides trust decentralization and confidentiality protection.[87]

Figure 6: Secure Multiparty Computations

Source: Unbound Security[88]

[79] James Scheibner and others, 'Revolutionizing Medical Data Sharing Using Advanced Privacy-Enhancing Technologies: Technical, Legal, and Ethical Synthesis' (2021) 23 Journal of Medical Internet Research e25120.
[80] Craig Gentry, 'Computing Arbitrary Functions of Encrypted Data' (2010) 53 Communications of the ACM 97, 1.
[81] Scheibner and others (n 79) 5.
[82] 'Data 2025 Session 2-The Use of Data for Healthcare and Pandemics' <https://www.youtube.com/watch?v=owMJ7iZLn60> accessed 19 August 2021.
[83] ibid.
[84] Celia Luterbacher, 'EPFL Software to Enable Secure Data-Sharing for Hospitals' <https://actu.epfl.ch/news/epfl-software-to-enable-secure-data-sharing-for-ho/> accessed 18 August 2021.
[85] ibid.
[86] ibid.
[87] Jean Louis Raisaro and others, 'MedCo: Enabling Secure and Privacy-Preserving Exploration of Distributed Clinical and Genomic Data' (2019) 16 IEEE/ACM Transactions on Computational Biology and Bioinformatics 1328, 1.
[88] Yehuda Lindell, 'Secure Multiparty Computation: Meaning, Protocol & MPC Cryptography' (*Unbound*, 23 May 2021) <https://www.unboundsecurity.com/blog/secure-multiparty-computation-mpc/> accessed 18 August 2021.

This technology is already in use by systems such as MedCo[89], Helen[90], and POSEIDON[91] to guarantee that all the information interchanged between sites is always in encrypted form, including aggregated data. For example, the MedCo system facilitates medical research on pathologies like cancer and infectious diseases by enabling secure computations—protecting patients' privacy—in a hybrid decentralized manner that overcomes the limitations of a fully centralized or decentralized approach.[92] This software was developed by EPFL's School of Computer and Communication Sciences (IC) in collaboration with the Lausanne University Hospital (CHUV) and has recently been deployed at three Swiss hospitals.[93]

Under the hybrid MedCo approach trust is not concentrated on a single central repository; instead, the trust is distributed among a set of different "storage and processing units" (SPUs) to which parties can securely outsource the storage of their data. Together, the SPUs form a secure, federated, and interoperable network where only authorized parties can request information as if it were a single unified database. The system allows parties to choose their preferred SPUs to reduce maintenance costs. Thus, the hosting of the SPU can be done by the parties with enough resources at their facilities, or it can be outsourced to another institution for parties with limited resources.[94] Each party could have its own SPU, or multiple parties can share the same SPU. In the end, all SPUs are arranged in a peer-to-peer network which forms a collective authority.[95] Confidentiality is guaranteed as the keys are collectively encrypted, thus preventing single points of failure and decryption without the cooperation of all SPUs[96]—none of the SPUs alone, even if compromised, can decrypt the data stored at its facilities.[97] Thus, SPUs are responsible for the security of the data stored and the secure processing of a query by an authorized user.[98] Additionally, under the MedCo system, only the user issuing the query can decrypt and "see" the results (e.g., aggregated data), and different levels of access privileges can be provided to different users.[99]

In sum, the MedCo system can deliver (1) trust decentralization, this is that there is no single point of failure in the system; (2) end-to-end data protection, which means that the confidentiality of the data in the SPUs is protected when inactive, in transit and during computations; (3) un-linkability, to prevent any user to trace a query response back to its original site; and (4) result obfuscation, where the query result is obfuscated to prevent reverse engineering originating from the behaviour of malicious or curious users that

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[89] MedCo is the first operational system that enables a group of clinical sites to federate and collectively protect their data in order to share them with external investigators without worrying about security and privacy concerns of health-data. MedCo enables secure and privacy-preserving exploration of distributed clinical and genomic data. Raisaro and others (n 87).

[90] A system that allows multiple parties to train a linear model without revealing their data. Wenting Zheng and others, 'Helen: Maliciously Secure Coopetitive Learning for Linear Models', *2019 IEEE Symposium on Security and Privacy (SP)* (2019) 1.

[91] POSEIDON is a privacy-preserving federated neural network learning. Sinem Sav and others, 'POSEIDON: Privacy-Preserving Federated Neural Network Learning' [2021] arXiv:2009.00349 [cs] <http://arxiv.org/abs/2009.00349> accessed 18 August 2021.

[92] The centralized approach provides advantages in terms of availability and flexibility, but it introduces a single point of failure in the system by accumulating all the trust on a single SPU. On the other hand, the fully decentralized approach solves the single-point-of-failure issue since it allows the parties to individually enforce local control on their data. However, this decentralization imposes substantial costs on the parties, as they have to maintain an interoperable network. Raisaro and others (n 87) 1–2.

[93] Luterbacher (n 84).

[94] Raisaro and others (n 87) 2.

[95] ibid 4.

[96] ibid 9.

[97] ibid 2.

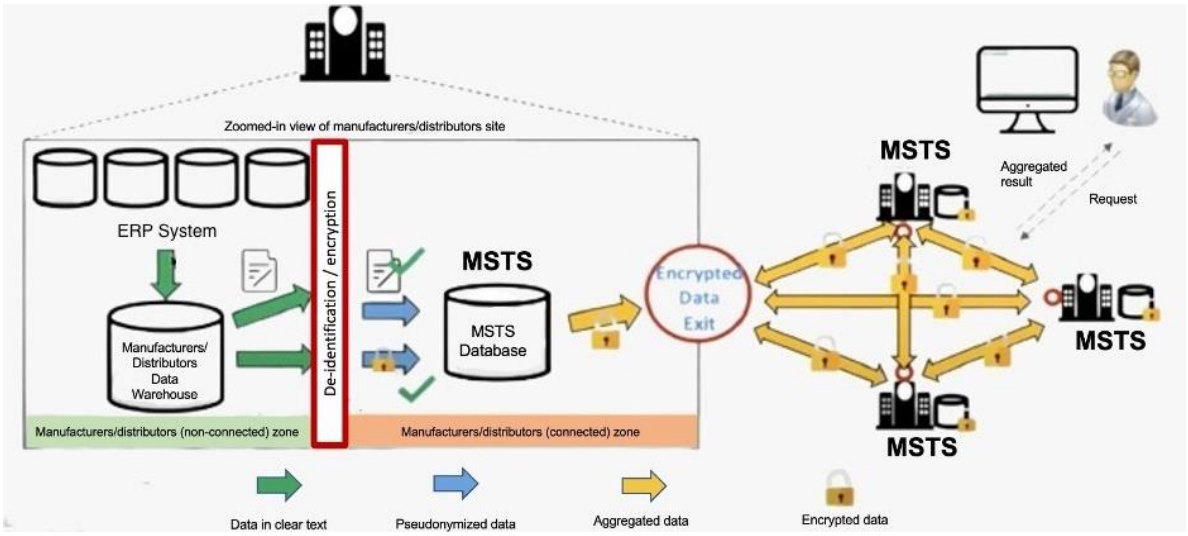
[98] ibid 4.

[99] ibid 5.

try to abuse the querying system. [100] Conceivably, each country could have a national SPU, which the government, private/public institutions, or non-profit organizations could administer. Under this scenario, all parties within the same country can outsource their data to this national SPU. Then, each country's national SPUs could combine to form an international, secure, and distributed network.[101] Accordingly, a system based on multiparty homomorphic encryption, such as the MedCo system, could provide effective, scalable, and practical solutions for addressing the data security issues that may prevent manufacturers sharing PPE supply data.

Considering the above, we firmly believe that the MedCo approach is a viable alternative to aggregate PPE supply data in a security-conscious and regulatory-compliant way.[102] In addition to implementing similar software like that used by MedCo in our system (MSTS), we suggest a data minimization approach to gather information. This entails collecting the bare minimum needed to get an aggregated estimate of PPE supply to soothe distributors' and manufacturers' security concerns. Accordingly, information regarding company identity such as the company's name, address, tax ID, or else not related to the system's mission would not be collected. The only information collected would be current production output, maximum productive capacity, and available inventory. After this quantitative information is gathered, multiparty homomorphic encryption would be used to enable secure data flows between MSTS's databases at manufacturers', distributors' and/or governments' facilities (Figure 7). This would allow MSTS's algorithms to generate supply-side market information without compromising data's confidentiality. The MSTS would not be able to see the data but would be able to aggregate it and produce an encrypted output that only parties with the "key" would be able to see.

Figure 7: MSTS Installed at Manufacturers', Distributors' and/or Governments' Premises



Source: Adapted from "The Use of Data for Healthcare and Pandemics"[103]

[100] ibid 2, 5.
[101] ibid 2.
[102] ibid 13.
[103] 'Data 2025 Session 2-The Use of Data for Healthcare and Pandemics' (n 82).

The MSTS could be hosted by research centres at academic institutions with relevant capabilities in cooperation with the WTO and WHO. For example, the Centre for Trade and Economic Integration at the Graduate Institute and the Center for Digital Trust at EPFL—both part of the Trust Valley public-private partnership located in politically neutral Switzerland. The Swiss Trust Valley is a public-private partnership launched by the cantons of Vaud and Geneva to promote excellence in digital trust and cybersecurity. This initiative relies on more than 500 experts, allowing for collaboration and synergies between universities and research institutes by drawing on their international recognition and strong complementarity.[104] The WTO and WHO headquarters located in Geneva provide an extraordinary opportunity to benefit from the Swiss Trust Valley to collaborate to implement the MSTS to provide publicly accessible PPE supply information.

5.3 Governmental buttress

Information pooling and dissemination have proven to be substantially beneficial in mitigating the trade costs of the COVID-19 pandemic. Multilateral and regional entities, as well as national governments, have adopted initiatives to combat information gaps caused by pandemic disturbances. These include the COVID-19 vaccine information platform[105] and the WTO's portal on COVID-19 related measures. These examples highlight the value of information sharing. Replication of such efforts to improve the transparency of PPE market supply within the WTO and WHO frameworks would be especially beneficial for future crisis preparedness.

In light of the above, this article proposes the MSTS to be harboured under the umbrella of the WTO/WHO frameworks. Given the imperative need to have governments' buttress to the successful implementation of the MSTS, the broad membership of the WTO and WHO, and the importance of data for trade efficiency and transparency to fight a pandemic, we argue that the WTO and WHO have the institutional capacity and mandate to launch a WTO/WHO joint initiative to govern the liberalisation of PPE market supply data. Notably, this would set an encouraging precedent for the WTO to play a central governance role in a future defined by exponentially expanding information flows. Accordingly, we propose three alternatives for participating Members to operate the MSTS:

- Option A: to instal the SPUs on governments' preferred hosting institutions (e.g., private/public institutions, non-profit organizations, and/or the government itself).
- Option B: to install the SPUs directly at public and private companies' premises.
- Option C: for large firms with enough resources, install the SPUs at their premises; for smaller firms, outsource the SPUs to designated host institutions.

[104] The Trust Valley, 'Trust Valley - An Alliance for Excellence in Digital Trust & Cybersecurity' (*Trust Valley*) <https://trustvalley.swiss/en/> accessed 23 August 2021.
[105] IISD's SDG Knowledge Hub, 'New Interagency Website Serves as Platform for Vaccine Information | News | SDG Knowledge Hub | IISD' <http://sdg.iisd.org/news/new-interagency-website-serves-as-platform-for-vaccine-information/?utm_medium=email&utm_campaign=Trade%20and%20SD%20Update%20-%205%20August%202021&utm_content=Trade%20and%20SD%20Update%20-%205%20August%202021+CID_f682c33afb03b0c4b13f29efc4ee12e1&utm_source=cm&utm_term=Read> accessed 7 August 2021.

Under all options, all SPUs would communicate to compute and provide aggregated outputs on PPE supply data. We present these three options so each government can decide which system works best according to its capacities and capabilities. The options here offered are not mutually exclusive: if one government chooses option A and another one option B, the system can still perform computations and achieve its mission.

In addition, we leave it to governments' discretion the level of aggregation they desire the system to compute. For instance, governments could decide to depart from a global level of aggregation approach and gradually move towards a regional or national level. It is expected that governments' trust in the system will require time, which hopefully will be on humanity's side. Hence, the system would become fully operational before the next pandemic strikes.

On the other hand, it bears to mention that manufacturers may be tempted to provide false information. A party could feed the system misleading information (e.g., report only 90% of their actual inventory) in an attempt to play the system and get the aggerated result to which they would only need to add their "unreported" 10%. However, although we acknowledge this is a possibility, the fact is that if multiple parties provide inaccurate information, the benefit of this behaviour becomes null for all parties as it would be impossible to estimate how many parties reported incorrect information and by what percentage.

Furthermore, to incentivize parties to share information, we propose that governments introduce advance procurement commitments to participating manufacturers (e.g., contingency contracts for parties that commit to sharing information)[106] or other financial incentives (e.g., tax benefits). Concomitantly, governments could establish domestic mechanisms to oversee that parties' reported information is accurate and to reward conforming parties. In addition, participating Members could introduce in the future a system of checks and balances (e.g., under Trade Policy review of countries, or by secretariat reports) to detect data inconsistencies.

5.4 Enhancing Transparency Provisions for Times of Crisis

In times of emergency, countries' responses change rapidly and often unpredictably, shrouding economic agents in uncertainty. As stressed throughout this paper, one of the most critical hindrances when designing policy responses to tackle a crisis is the lack of timely and updated information. To remedy these weaknesses, we have proposed in section 5.1 the creation of the MSTS: a secure, public, digital system that aggregates real-time PPE market supply data from PPE manufacturers, distributors and/or governments. To collect the necessary information to operate the system, it is essential to have the government's commitment to instruct relevant public and private agents to collaborate on the generation of timely and accurate data on PPE supply.

In this context, though rules and provisions on transparency appear in WTO covered agreements, such disciplines are ill-suited to deal with crises. Moreover, while common in trade agreements, transparency provisions

[106] He and others (n 66) 1707.

proved insufficient to address the need for PPE supply data during COVID-19. Notably, while the Agreement on Trade Facilitation (TFA) provides a baseline to share information on procedures for the importation, exportation, and transit of goods, as well as relevant trade-related legislation, there are no specific provisions to share relevant information on essential goods in times of crisis. [107] Thus, cooperation and information pooling mechanisms would be one area for enhancing cooperation and crisis-proofing trade agreements. [108] Accordingly, a WTO/WHO joint initiative, centred around secretariats who would then reach out to Members willing to participate, could prompt cooperation among countries to make further trade-related information on PPE supply available.

The Sample WTO/WHO Joint Initiative below proposes a commitment that would allow the use of pooled PPE supply data. Under Paragraph 3 of this initiative, participating Members would amend domestic regulations to support the operation of our proposed system so manufacturers, distributors and governments could host or designate a host for the MSTS's SPUs. However, action may be needed to increase the capacity of some Members to undertake systematic monitoring of the state of essential goods supply, such as PPE. Clearly, constructing a global PPE market information system will require capacity building and technical assistance for developing countries. In this context, the TFA's flexible implementation approach and its commitment to coordination and cooperation emerge as an appropriate starting point that could be improved even further.

Sample WTO/WHO Joint Initiative: Draft Decision by Interested Members

"1. Pandemics pose a serious global threat. The spread of COVID-19 has led to a devastating human tragedy and responding to this global health crisis remains a priority of our respective governments. Now more than ever is the time for the international community to step up cooperation and coordination.

2. We recognise that it is in our mutual interest to increase market supply transparency of Personal Protective Equipment (PPE) to facilitate better informed and coordinated policy decision-making and to prevent shortages that can make international prices volatile.

3. We call on governments to set up a system to share updated and accurate information on PPE supply. Parties to this initiative should make available, and update to the extent possible and as appropriate, information of domestic current production output, maximum productive capacity, and available inventory of the products of Section II of the Joint WCO/WHO HS Classification Reference For COVID-19 Medical Supplies 3.01 Edition.

4. We encourage all WTO and WHO Members to join us and support this initiative to enhance the benefits of sharing PPE supply data across the globe."

Source: Sample Draft Language

[107] Art. 1 of the TFA; 'Live Session 1-Pilot Course on Negotiating Regional Trade Agreements for Trade in Times of Crisis and Pandemics' (n 78).

[108] ibid.

On the other hand, some Members may already be taking steps to design domestic mechanisms to collect PPE supply data at a national level, such as the US.[109] This would make it easier for such Members to share their aggregated national information with the MSTS. However, where the mechanisms and institutions are not in place nationally, governments should undertake to create them in accordance with the fundamental principles of their legal systems. Furthermore, a WTO/WHO joint task force or similar could be set up to support and coordinate Member's efforts.

The WTO has a vital role in monitoring trade-related information and has recognized the importance of promoting open, transparent, non-discriminatory, and predictable regulatory environments. WTO Ministers are actively working to ensure the continuous flow of information needed in global emergencies and have been joining efforts with the WHO on a number of different issues related to trade and health. Against this backdrop, the WTO and WHO have a crucial role to play regarding PPE supply data by acknowledging that the interconnectedness and vulnerabilities of countries facing a pandemic require a coherent, multi-sectoral, multi-stakeholder, and WTO/WHO-wide approach.

Accordingly, the information produced by the MSTS should be open to all Members to build transparency and preparedness for future crises. The MSTS would allow Members to make informed policy decisions to:

- Improve preparedness on PPE supply for the next crisis.
- Contribute to exchanging timely and accurate PPE supply information during a crisis.
- Promote a coordinated global response on PPE shortages to tackle a crisis more efficiently.
- Promote coordination among Members to finance the expansion of the production capacity of manufacturers of PPE and the companies they source from.
- Promote coordination to pool international buying power to prevent hoarding and bidding wars among Members during a crisis. [110]

Based on countries' responses, MSTS can then be extended to include, for instance, PPE inputs or other essential goods in the future. It is important to stress that this is a pilot initiative to boost cooperation and transparency to fight a pandemic. Thus, we envision that the system could also integrate information related to policies that restrict, promote, diversify or concentrate the supply of PPE or other essential goods in the future. To achieve this, the system must remain flexible to promote continuous improvement to suit Members' needs.

[109] Cecire and others (n 3).

[110] García-Santaolalla (n 76) 24.

Conclusion

The threat of pandemics has increased as our world has become more interconnected. COVID-19 has highlighted the need for increased transparency and information sharing to increase the resilience of global supply chains during crises or emergencies, which ultimately saves lives. As we look ahead and begin to prepare for the next pandemic, public-private cooperation on enhancing information transparency will continue to be a critical component of this process as recognized by the WTO itself[111].

Therefore, this paper seeks to bring attention to and promote public-private collaboration on PPE supply data by discussing areas on which public and private organizations can focus their efforts to improve partnerships, as governments must effectively engage with firms to adopt an efficient, low-burden mechanism to share PPE supply data. The paper addresses this issue by proposing the creation of a secure, public, digital system that aggregates real-time PPE supply data for the benefit of all market actors and policymakers.

While the WTO has called for the creation of a global transparency mechanism for the production and trade for all essential goods[112], the MSTS applied to PPE within the WHO/WTO frameworks is politically viable now as it can be launched on a voluntary basis. Therefore, the MSTS could function as a pilot initiative to kickstart the future liberalization of a greater variety of trade-related information and may be broadened to cover other strategic goods and services with globalized supply chains, such as medical equipment and vaccines. In this sense, this paper should be interpreted as an initial, politically tentative proposal in response to the WTO's recommendation, with the hope that it may be broadened to enhance the resilience of other essential supply chains in the future.

While we hope this article will encourage effective collaboration between the public and private sectors, we acknowledge that motivating governments and firms to cooperate when dealing with common threats to provide a unified response is challenging. Often complacency and competing interests lead to insufficient political support to address major crises.[113] Conversely, crises ultimately provide signals that an existing order is no longer viable. The global health security community produces mounting evidence of the risks, impact, and unmet needs associated with infectious disease outbreaks, and the responsibility to better address these threats must be shared by public and private actors to ensure that when faced with the next health crisis, we are ready, together.[114]

[111] WTO (n 2).
[112] ibid.
[113] Rebecca Katz and others, 'Enhancing Public–Private Cooperation in Epidemic Preparedness and Response' (2018) 10 World Medical & Health Policy 420, 423.
[114] ibid.

APPENDIX A: WHO-WCO REFERENCE OF PPE GOODS IN THE CONTEXT OF COVID-19

Product	HS 2017 Classification
Face and eye protection	
Cellulose/paper masks	4818.90
Textile face-masks, without a replaceable filter or mechanical parts, including surgical masks and disposable face-masks made of non-woven textiles. This includes the masks known as N95 Particulate Respirators. Note: the heading also includes N95 respirators with simple exhalation valves as these remain respirator masks and are not gas masks.	6307.90
Gas masks with mechanical parts or replaceable filters for protection against biological agents. It also includes such masks incorporating eye protection or facial shields.	9020.00
Protective spectacles and goggles	9004.90
Plastic face shields (covering more than the eye area)	3926.90
Gloves	
Plastic gloves	3926.20
Surgical rubber gloves	4015.11
Other rubber gloves	4015.19
Knitted or crocheted gloves that have been impregnated or covered with plastics or rubber	6116.10
Textile gloves that are not knitted or crocheted	6216.00
Other	
Disposable hair nets	6505.00
“Scrub tops” – loose fit unisex tops, made of a tightly woven cotton or cotton blend (more than 50% cotton) fabric without any coating, covering or other treatment, identifiable as being of the kind used by medical staff in hospitals.	6211.42
“Scrub bottoms” – loose fit unisex long pants, made of a tightly woven cotton or cotton blend (more than 50% cotton) fabric without any coating, covering or other treatment, identifiable as being of the kind used by medical staff in hospitals.	6211.42

Protective unisex garments made of plastic sheeting, textile reinforced plastics or textile backed plastics.	3926.20
Protective unisex garments made of rubber sheeting, textile reinforced rubber or textile backed rubber.	4015.90
Paper or cellulose garments and clothing accessories such as disposable paper hospital gowns, paper shoe covers etc. These are covered here provided that they are made of paper, paper pulp, cellulose wadding or webs of cellulose fibres.	4818.50
Protective garments for surgical/medical use made up of felt or non-wovens whether or not impregnated, coated, covered or laminated (fabrics of heading 56.02 or 56.03). This includes spun-bonded garments.	6210.10
Men's protective garments for surgical/medical use made of woven textiles that are impregnated, coated, covered or laminated with plastics.	6210.40
Men's protective garments made of rubberized textile fabrics	6210.40
Women's or unisex protective garments for surgical/medical use made of woven textiles that are impregnated, coated, covered or laminated with plastics.	6210.50
Women's or unisex protective garments made of rubberized textile fabrics	6210.50
"Protective apron" – made of plastic, disposable	3926.20
Boot covers/overshoes – made of plastic or rubber, disposable	3926.90/4016.99
* Boot covers/overshoes – made of cellulose/paper, disposable	4818.90
* Boot covers/overshoes – made of non-woven textiles, disposable	6307.90

Source: World Customs Organization[115]

[115] WCO (n 7).

Bibliography

1. AMIS, 'Enhancing Market Transparency' (2011) <http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/reports/Improving_global_governance_for_food_security.pdf> accessed 23 August 2021
2. AMIS, 'Agricultural Market Information System: About' (2021) <http://www.amis-outlook.org/amis-about/en/> accessed 22 August 2021
3. Asian Development Bank and others, 'Global Shortage of Personal Protective Equipment amid COVID-19: Supply Chains, Bottlenecks, and Policy Implications' (Asian Development Bank 2020) <https://www.adb.org/publications/shortage-ppe-covid-19-supply-chains-bottlenecks-policy> accessed 23 August 2021
4. BDI, 'Export Controls and Export Bans over the Course of the COVID-19 Pandemic' (2020) <https://www.wto.org/english/tratop_e/covid19_e/bdi_covid19_e.pdf>
5. Bloom DE and Cadarette D, 'Infectious Disease Threats in the Twenty-First Century: Strengthening the Global Response' (2019) 10 Frontiers in Immunology <https://www.frontiersin.org/article/10.3389/fimmu.2019.00549/full> accessed 23 August 2021
6. Bown CP, '21-11 How COVID-19 Medical Supply Shortages Led to Extraordinary Trade and Industrial Policy' 30
7. Burki T, 'Global Shortage of Personal Protective Equipment' (2020) 20 The Lancet Infectious Diseases 785
8. Casey CA and Cimino-Isaacs CD, 'Export Restrictions in Response to the COVID-19 Pandemic' [2021] Congressional Research Service 3
9. Cecire M, 'COVID-19 and Domestic PPE Production and Distribution: Issues and Policy Options' (Congressional Research Service, 2020) <https://crsreports.congress.gov/product/pdf/R/R46628>
10. Cecire MH and others, 'COVID-19 and Domestic PPE Production and Distribution: Issues and Policy Options' [2020] Congressional Research Service 71
11. Chowdhury P and others, 'COVID-19 Pandemic Related Supply Chain Studies: A Systematic Review' (2021) 148 Transportation Research Part E: Logistics and Transportation Review 102271
12. CRS, 'Export Restrictions in Response to the COVID-19 Pandemic' (2021) <https://crsreports.congress.gov/product/pdf/IF/IF11551>
13. Dai T and others, 'Supply Chain Failures amid Covid - 19 Signal a New Pillar for Global Health Preparedness' (2021) 30 Journal of Clinical Nursing <https://onlinelibrary.wiley.com/doi/10.1111/jocn.15400> accessed 23 August 2021
14. Dai T, Bai G and Anderson GF, 'PPE Supply Chain Needs Data Transparency and Stress Testing' (2020) 35 Journal of General Internal Medicine 2748
15. 'Data 2025 Session 2-The Use of Data for Healthcare and Pandemics' <https://www.youtube.com/watch?v=owMJ7iZLn60> accessed 19 August 2021
16. DeCarlo S, 'COVID-19 Related Goods: The U.S. Industry, Market, Trade, and Supply Chain Challenges' 4
17. EIF, 'Unpacking COVID-19-Related Medical Supply Chains in Commonwealth LDCs' (Trade 4 Dev News, 14 July 2020) <https://trade4devnews.enhancedif.org/en/op-ed/unpacking-covid-19-related-medical-supply-chains-commonwealth-ldcs> accessed 23 August 2021

18. Evstatieva M, 'U.S. Companies Shifted To Make N95 Respirators During COVID. Now, They're Struggling' (NPR.org) <https://www.npr.org/2021/06/25/1009858893/u-s-companies-shifted-to-make-n95-respirators-during-covid-now-theyre-struggling> accessed 23 August 2021
19. Finkenstadt DJ and Handfield R, 'Blurry Vision: Supply Chain Visibility for Personal Protective Equipment during COVID-19' (2021) 27 Journal of Purchasing and Supply Management 100689
20. Fu J, McMahon JA and Xue H, 'More Restriction or Facilitation on PPE amid COVID-19: Limitations and Options of International Trade Law' (2020)
21. G20, 'Ministerial Declaration: Action Plan on Food Price Volatility and Agriculture' (2011) <http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/2011-agriculture-plan-en.pdf>
22. Garcia-Santaolalla N, 'Obstáculos que Enfrentan los Países Actualmente para Proveer al Sector Salud y a la Sociedad en General de Insumos Médicos Esenciales para Hacer Frente a la Pandemia' (Tecnológico de Monterrey: Investigación de COVID-19 en México, 2020) <https://mexicovid19.app/> accessed 26 July 2020
23. García-Santaolalla N, 'A Proposal to Reform "Security-Emergency" Exceptions in Trade' (ESCAP Online Repository of Contributions to the Policy Hackathon on Model Provisions for Trade in Times of Crisis and Pandemic) <https://www.unescap.org/resources/online-repository-contributions-policy-hackathon-model-provisions-trade-times-crisis-and> accessed 19 August 2021
24. Gentry C, 'Computing Arbitrary Functions of Encrypted Data' (2010) 53 Communications of the ACM 97
25. He S and others, 'Effective Supply Chain Surveillance for PPE' (2021) 397 The Lancet 1706
26. Health C for D and R, 'Personal Protective Equipment for Infection Control' (FDA, 11–38 May 2020) <https://www.fda.gov/medical-devices/general-hospital-devices-and-supplies/personal-protective-equipment-infection-control> accessed 23 August 2021
27. 'Health Systems in Low-Income Countries Will Struggle to Protect Health Workers from COVID-19' (Center For Global Development) <https://www.cgdev.org/blog/health-systems-low-income-countries-will-struggle-protect-health-workers-covid-19> accessed 23 August 2021
28. 'Henry Schein Named to Fortune® Magazine's "Change the World" List | Henry Schein' <https://investor.henryschein.com/news-releases/news-release-details/henry-schein-named-fortuner-magazines-change-world-list> accessed 18 August 2021
29. Hoyama T and Hosokawa R, 'Reliance on Chinese Protective Gear Soars in Pandemic's Wake - Nikkei Asia' <https://asia.nikkei.com/Spotlight/Coronavirus/Reliance-on-Chinese-protective-gear-soars-in-pandemic-s-wake> accessed 23 August 2021
30. Hub ISK, 'New Interagency Website Serves as Platform for Vaccine Information | News | SDG Knowledge Hub | IISD' <http://sdg.iisd.org/news/new-interagency-website-serves-as-platform-for-vaccine-information/?utm_medium=email&utm_campaign=Trade%20and%20SD%20Update%20-%205%20August%202021&utm_content=Trade%20and%20SD%20Update%20-%205%20August%202021+CID_f682c33afb03b0c4b13f29efc4ee12e1&utm_source=cm&utm_term=Read> accessed 7 August 2021
31. IFC, 'Covid-19 PPE Demand and Supply Perspectives' (2020) <https://www.ifc.org/wps/wcm/connect/1d32e536-76cc-4023-9430-1333d6b92cc6/210302_FCDO_GlobalPPE_Final+report_v13_gja.pdf?MOD=AJPERES&CVID=nvPXlAZ> accessed 23 August 2021
32. ITC, 'Trade Map - Trade Statistics for International Business Development' <https://www.trademap.org/Index.aspx> accessed 23 August 2021

33. Katz R and others, 'Enhancing Public–Private Cooperation in Epidemic Preparedness and Response' (2018) 10 World Medical & Health Policy 420

34. Lindell Y, 'Secure Multiparty Computation: Meaning, Protocol & MPC Cryptography' (Unbound, 23 May 2021) <https://www.unboundsecurity.com/blog/secure-multiparty-computation-mpc/> accessed 18 August 2021

35. 'Live Session 1-Pilot Course on Negotiating Regional Trade Agreements for Trade in Times of Crisis and Pandemics' <https://www.youtube.com/watch?v=SAgPfCC0O1o&list=PLgTVHD_RzYIMjVS6xrDxg6g8XLpkbco3t&index=11> accessed 19 August 2021

36. Luterbacher C, 'EPFL Software to Enable Secure Data-Sharing for Hospitals' <https://actu.epfl.ch/news/epfl-software-to-enable-secure-data-sharing-for-ho/> accessed 18 August 2021

37. Mcevoy E and Ferri D, 'The Role of the Joint Procurement Agreement during the COVID-19 Pandemic: Assessing Its Usefulness and Discussing Its Potential to Support a European Health Union' (2020) 11 European Journal of Risk Regulation 851

38. McMahon DE and others, 'Global Resource Shortages during COVID-19: Bad News for Low-Income Countries' (2020) 14 PLOS Neglected Tropical Diseases e0008412

39. Mehrotra P, Malani P and Yadav P, 'Personal Protective Equipment Shortages During COVID-19—Supply Chain–Related Causes and Mitigation Strategies' (2020) 1 JAMA Health Forum e200553

40. OSHA, 'Personal Protective Equipment - Overview | Occupational Safety and Health Administration' <https://www.osha.gov/personal-protective-equipment> accessed 23 August 2021

41. Raisaro JL and others, 'MedCo: Enabling Secure and Privacy-Preserving Exploration of Distributed Clinical and Genomic Data' (2019) 16 IEEE/ACM Transactions on Computational Biology and Bioinformatics 1328

42. Sav S and others, 'POSEIDON: Privacy-Preserving Federated Neural Network Learning' [2021] arXiv:2009.00349 [cs] <http://arxiv.org/abs/2009.00349> accessed 18 August 2021

43. Scheibner J and others, 'Revolutionizing Medical Data Sharing Using Advanced Privacy-Enhancing Technologies: Technical, Legal, and Ethical Synthesis' (2021) 23 Journal of Medical Internet Research e25120

44. The Trust Valley, 'Trust Valley - An Alliance for Excellence in Digital Trust & Cybersecurity' (Trust Valley) <https://trustvalley.swiss/en/> accessed 23 August 2021

45. Trading Economics, '20 Million Indicators from 196 Countries' <https://tradingeconomics.com/> accessed 23 August 2021

46. 'Vaccinating the World: From Mass Production to Last-Mile Delivery (Option 2) - English' <https://www.weforum.org/videos/davos-2021-vaccinating-the-world-from-mass-production-to-last-mile-delivery-option-2-english/> accessed 18 August 2021

47. Walsh M and VanderKlippe N, 'Ottawa and the Provinces Are Navigating a "Wild West" in the Medical Supply Market - The Globe and Mail' <https://www.theglobeandmail.com/politics/article-ottawa-and-the-provinces-are-navigating-a-wild-west-in-the-medical/> accessed 23 August 2021

48. WCO, 'HS Classification Reference for Covid-19 Medical Supplies 3.01 Edition' <http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/nomenclature/covid_19/hs-classification-reference_edition-3_en.pdf?la=en> accessed 17 September 2021

49. WEF, 'Pandemic Supply Chain Network (PSCN)' (World Economic Forum) <https://www.weforum.org/projects/pandemic-supply-chain-network-pscn/> accessed 19 August 2021

50. WFP, 'Innovative Supply Chain Information Platform Will Help Prepare For The Next Pandemic | World Food Programme' (2017) <https://www.wfp.org/news/innovative-supply-chain-information-platform-will-help-prepare-next-pandemic> accessed 22 August 2021
51. WHO, 'Technical Specifications of Personal Protective Equipment for COVID-19' <https://www.who.int/publications-detail-redirect/WHO-2019-nCoV-PPE_specifications-2020.1> accessed 17 August 2021
52. WTO, 'Trade in Medical Goods in the Context of Tackling COVID-19' (2020) <https://www.wto.org/english/news_e/news20_e/rese_03apr20_e.pdf> accessed 23 August 2021
53. WTO, 'Improving Trade Data for Products Essential to Fight COVID-19: A Possible Way Forward' (2021) <https://www.wto.org/english/tratop_e/covid19_e/trade_data_report_e.pdf>
54. Zheng W and others, 'Helen: Maliciously Secure Coopetitive Learning for Linear Models', 2019 IEEE Symposium on Security and Privacy (SP) (2019)