Received: 12 December 2021 | Revised: 4 May 2022 | Accepted: 7 May 2022

DOI: 10.1111/1758-5899.13103

POLICY INSIGHTS

Ensuring Market Supply Transparency for Personal Protective Equipment: 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 in preparation for the next pandemic.

1 | INTRODUCTION

The COVID-19 pandemic has exposed the opacity of the global personal protective equipment (PPE) supply chain. Dependence on international markets for PPE provision has rendered 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 export bans. These aggravated the supply deficit, led to severe price inflation, and significantly undermined public health responses. With the pandemic having revealed the integral role of trade in dealing with global crises, recovery measures and preparation for future crises must look to enhance the resilience of the global PPE supply chain.

To this end, the World Trade Organisation (WTO) has argued that enhancing supply chain transparency through data sharing is a global public good necessary for future pandemic preparedness: 'To the extent possible, [WTO members could] 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, [WTO members

could] try to establish a mechanism by which private companies can voluntarily share relevant information'.

Drawing from lessons learnt during the pandemic, this paper proposes the creation of a global market supply transparency system (MSTS) for PPE. In making this proposal, the paper proceeds in five sections. Section 1 provides an introductory overview of the impact of COVID-19 on the supply of PPE to international markets, Section 2 outlines key facts and figures about the global PPE market in the context of COVID-19, and Section 3 discusses the dearth of information on PPE production and its consequences for policy responses throughout the pandemic. Section 4 draws from the prior contextual sections to analyse lessons learned from lack of supply-side information and examines two past approaches to enhance supply transparency: the Agricultural Market Information System (AMIS) and the Pandemic Supply Chain Network (PSCN). Finally, Section 5 recommends the creation of a market supply transparency mechanism for PPE.

1.1 | Defining PPE

In the context of the COVID-19 pandemic, the World Health Organisation (WHO) and World Customs Organisation (WCO) have provided guidance as to what should be considered crucial PPE. This includes surgical face masks and N95 respirators,[1] protective spectacles and goggles, plastic face shields, gloves, hair nets, surgical gowns, and other protective garments (WCO, 2020). 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 Harmonised System (HS) classification reference list for COVID-19 medical supplies, Section II: Protective garments and the like.[2]

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 in a context of disrupted global supply chains (McEvoy & Ferri, 2020). Exponential growth in domestic demand for PPE in the first half of 2020 prompted most PPE producing nations to implement export restrictions. Taiwan became the first country to implement restrictions on 24 January 2020 (OECD, 2020), while the United States implemented restrictions on the export of PPE in April 2020 with special exemptions for exports to US humanitarian missions, Canada, and Mexico (Casey & Cimino-Isaacs, 2021). In March 2020, many European countries unilaterally implemented export restrictions on the intra and extra-EU export of PPE. The European Commission quickly dissolved restrictions on intra-EU PPE exports but implemented an exceptionally restrictive PPE export licensing scheme which effectively amounted to an extra-EU export ban (Bundesverband der Deutschen Industrie (BDI), 2020). Most significantly, in early February 2020, China nationalised control over the domestic production and distribution of PPE, diverting export bound PPE to meet domestic demand through procurement measures (Feinmann, 2020). This was followed by the imposition of new export licensing requirements in April 2020. While this was reportedly done to ensure the quality of exported PPE, some analysts contend it restricted PPE exports to allow the Chinese government to orchestrate selective PPE deliveries to specific countries for political gain (Cecire, 2020; Ranney et al., 2020).

By June 2020, 47 countries had notified the WTO of restrictions on PPE exports, although the number of de facto export restrictions was likely to be much higher given the poor state of notifications at the WTO (Fu et al., 2020). In the short run, export restrictions in PPE producing nations increase domestic supply and reduce domestic prices but may lead to shortages in international markets and inflated international prices in the long run. Additionally, export restrictions may prompt a knock-on effect of inducing other countries to implement their own export restrictions, which exacerbates these shortages (Casey & Cimino-Isaacs, 2021). Consequently, the domino effect of export restrictions which unfolded in 2020 created substantial uncertainty and volatility in the international PPE market, thereby undermining the global health response to the pandemic.

2 | CONTEXTUALISING THE GLOBAL PPE MARKET

China is the world's largest producer of PPE having produced 40 to 60 per cent of global PPE prior to COVID-19 (International Finance Corporation [IFC], 2020). After the pandemic broke, China rapidly increased PPE production to supply as much as 83 per cent of PPE to global markets in May of 2020 (Hoyama & Hosokawa, 2020) and around 80 per cent in 2020 overall (Finkenstadt & Handfield, 2021). This dwarfs the US's share of production, which prior to the pandemic stood at 20 to 25 per cent of global PPE (IFC, 2020).

While demand spikes and supply shortages incentivised investment into the local manufacture of PPE in many countries, low longevity of heightened demand has forced many of these producers to subsequently shut down due to their inability to compete with cheaper Chinese imports (Evstatieva, 2021). Therefore, rather than diversifying and reshoring PPE supply chains, the pandemic may entrench dependence on global markets for domestic PPE provision. As a result, trade in

PPE surged by 433 per cent, from $20.9 billion in 2019 to $90.5 billion in 2020, with China unsurprisingly dominant as the primary supplier for nine of the top 10 PPE importers (WTO, 2020).

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. Although these questions are crucial for policy makers to assess the vulnerability of domestic PPE supply, they are unable to do so given the lack of domestic, regional, and global PPE supply transparency.

3 | THE DEARTH OF INFORMATION ON PPE SUPPLY AND ITS IMPACT

3.1 | International markets

Personal protective equipment shortages have exposed the hyper globalised nature of the PPE supply chain and revealed the vulnerability of PPE supply to changes in national politics. While supply vulnerability of strategic goods such as PPE is clearly problematic, policy makers 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 policy makers make underinformed decisions and may implement hasty and uncoordinated measures which exacerbate market volatility, such as export restrictions. 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' (Walsh & VanderKlippe, 2020), with accusations of 'modern piracy' abounding as countries impounded cargo planes, purchasers offered cash to divert en route PPE shipments, and policy makers strategically confiscated export bound PPE (Feinmann, 2020; McMahon et al., 2020).

3.2 | Domestic market case study: United States of America

The lack of information on PPE supply stems from the reticence of manufacturing firms to share production data which they consider proprietary information. Additionally, within the US and most countries around the world, no legal or institutional mechanism exists to compel manufacturers to share this data, such as manufacturing capacity, output, and available inventory. Therefore it is extremely difficult to discern the degree to which domestic PPE demand is met through local manufacturing or imports (Bown, 2021), which may cause policy makers to exacerbate shortages (Cohen & van der Meulen Rodgers, 2020). For example, US tariffs on Chinese PPE imports increased prices by up to 25 per cent, yet, while US demand for PPE quadrupled by February 2020, these tariffs were only lifted in March of that same year (Cohen & van der Meulen Rodgers, 2020; DeCarlo, 2020). A study conducted on the US PPE supply chain in 2020 – which examined 5 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 (Dai et al., 2020).

As part of a review of the US government's pandemic response, policy makers 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 (DeCarlo, 2020). The inquiry found that the US relies on imports for 80–90 per cent of its PPE supply, 75 per cent 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 (DeCarlo, 2020). Therefore, domestic production was grossly insufficient to meet surging demand at the onset of the pandemic. For instance, the US required 1.8 billion gloves per week but was only producing 500 million gloves annually (Bown, 2021). At the same time, 40 per cent of medical facilities were unable to obtain N95 masks in the first half of 2020 (Finkenstadt & Handfield, 2021), as 95 per cent of N95 masks were imported from China (DeCarlo, 2020). Severe shortages led to delays of 3 to 6 months for urgently required PPE (Bown, 2021), with 87 per cent of nurses surveyed reported having to reuse disposable masks (Cohen & van der Meulen Rodgers, 2020), and doctors and hospitals resorting to sourcing PPE through personal networks (Mehrotra et al., 2020) and through broad social media appeals (Ranney et al., 2020). Thus, 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 (DeCarlo, 2020).

To try and overcome the shortfall, the US government deployed a total of $1.2 billion in subsidies to scale up domestic PPE production in 2020. However, due to a lack of information on domestic PPE production, the deployment of subsidies was delayed as policy makers struggled to determine where they should be targeted and what sums were appropriate (Bown, 2021). The

congressional report concluded that a lack of production data severely hindered effective policy responses, noting that its own findings were reliant upon production data from 2017 (DeCarlo, 2020). This would explain the government's failure to coordinate domestic production and distribution on a federal level, something for which it has received widespread criticism (Cohen & van der Meulen Rodgers, 2020; Patel et al., 2017). Therefore, 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' (Bown, 2021).

4 | LESSONS LEARNED

4.1 | The imperative need for PPE market supply transparency

Publicly available information on global PPE supply is a market enhancing mechanism and global public good for 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 (AMIS, 2011). The Asian Development Bank (ADB) 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 … An efficient, low burden mechanism for governments and private sector partners to share situational and supply information needs to be developed' (Park et al., 2020).

Creating such a system would facilitate a cooperative and coordinated response between countries based on transparency which would likely do much to calm international market volatility and prevent the imposition of knee-jerk export restrictions in the future (Bown, 2021; OECD, 2020). Preventing future volatility would reduce instances of panic buying and hoarding, thereby ensuring price stability which is ultimately to the benefit of consumers (AMIS, 2011). 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 (Chowdhury et al., 2021; UNCTAD, 2020). For policy makers, 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 (He et al., 2021). Hence, a PPE MSTS would constitute a way to overcome market inefficiencies and distortions through a non-market-distorting measure by enabling the efficient allocation of PPE supply and capital.

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 2007–08 global food crisis, during which unexpected price hikes on foodstuffs led to export restrictions, hoarding and widespread food insecurity. In response, ten international organisations and other actors identified 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 as primary causes of the crisis (G20, 2011). This led to the creation of 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 (AMIS, 2011). Since its creation, AMIS has enhanced transparency and policy coordination in international food markets, which has helped prevent price spikes and strengthen global food security (AMIS, 2021).

Second, the Pandemic Supply Chain Network (PSCN) was established at the World Economic Forum (WEF) in Davos in 2015 (WEF, 2021) 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 in their provision (WFP, 2017). The PSCN brought together the private sector and global organisations such as the WHO, WEF, the World Bank, the United Nations Children's Fund (UNICEF), the World Food Programme (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 (WFP, 2017). In the context of COVID-19, the PSCN has been described as 'an *informal group* [emphasis added] of public-private partnership activities that relate to the 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' (Bergman, 2021).

Henry Schein, 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' (Henry Schein, Inc., 2020). However, initiatives such as the PSCN are in their early stages of implementation and do not represent the finalised construction of a predictable, dependable and effective system (The Independent Panel for Pandemic Preparedness and Response, 2021). For instance, despite the existence of the PSCN since 2015, the chronic lack of PPE supply-side information persisted throughout the pandemic. According to Stanley M. Bergman, Chairman of the Board and CEO of Henry Schein Inc, a lack of collaboration from the public and private sectors hindered the PSCN's effectiveness because the PSCN is 'not a government' but only an informal 'group of people' (Bergman, 2021).

In this context, while the systems for advancing health security are progressing in the right direction, their potential vulnerabilities must continue to be monitored and improved (The Independent Panel for Pandemic Preparedness and Response, 2021). Accordingly, this study aims to build on previous efforts by proposing a highly flexible system that can work jointly with or independently of other initiatives (such as the PSCN) to boost public-private collaboration by facilitating secure information sharing and improving transparency in the global PPE supply chain.

5 | A WAY FORWARD

Personal protective equipment supply data is critical to any health emergency intervention because inadequate preparedness and response capacity results in delays, costs lives and wastes vital resources. Drawing on lessons learnt from COVID-19, AMIS and the PSCN, this paper proposes the creation of the PPE MSTS, which would leverage current cloud computing and encryption technologies to provide real-time information on PPE supply to policy makers and manufacturers. 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 establishing such a system to collect PPE market supply data successfully. First, the need for governmental support to incentivise companies to share what they consider proprietary production 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 informal discussions with an AMIS participant and an École Polytechnique Fédérale de Lausanne (EPFL) information security expert.

5.1 | The market supply transparency system

Policy decisions to fight a health crisis should be based on timely and credible information on domestic and global PPE supplies and prices. However, even though the world has experienced several outbreaks over the last two decades, 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, and the Coronavirus in 2019 (COVID-19), this information deficit continues to persist.

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 pandemics but will likely have the opposite effect since participation in global supply chains is needed to alleviate 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 benefit from reshoring PPE supply chains (Evenett, 2021).

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 discussed 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 may 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. However, judging from the number of proposals on trade and health issues at the WTO, the G7, G20, and other international organisations, our understanding is that there is immense political will to improve transparency to enhance resilience and preparedness against future pandemics.

For instance, a recent proposal for a General Council Declaration submitted by 32 WTO members (including Australia, Brazil, Canada, Chile, China, Costa Rica, the European Union, Hong Kong, China, Japan, Korea, Mexico, New Zealand, Norway, Qatar, Saudi Arabia, Singapore, Switzerland, Taiwan, the United Kingdom and Uruguay) acknowledges significant data gaps concerning the production, demand and supply of essential medical goods. As a result, this proposal includes a commitment to make every effort to provide the relevant data to the WTO. However, the text of this proposal introduces two caveats that deserve attention: (1) the effort to provide information is subject to a request from the Secretariat; and (2) such information will be shared to the extent possible and practicable, and subject to commercial confidentiality (WTO, 2021). Thus, to address these types of reservations and catalyse these and other similar ideas and efforts, we introduce the MSTS: a voluntary transparency system that can be implemented from the national to the international level.

5.2 | Data security

In the last few years, developments in cryptographic privacy-enhancing technologies have significantly undermined certain data security concerns related to encryption. 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 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 (Scheibner et al., 2021). As a result, homomorphically encrypted data can be securely delivered to third parties that can perform meaningful operations on it without knowing anything about the content of the data. In short, this means that a third party can process data without being able to 'see it' (Gentry, 2010). 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 (Scheibner et al., 2021). Therefore, when multiple parties are involved (e.g. PPE manufacturers, distributors, or governments), it is possible to perform computations on data without collection and centralisation. During these computations, the sole 'kind of exchange' between parties consists of the algorithm transferring to the various loci of the data and not the other way around – and in the end, each party can only access the aggregated output (Hubaux, 2020).

Both secure multiparty computation and homomorphic encryption are complementary encryption techniques that rely upon mathematically proven guarantees of data confidentiality (Scheibner et al., 2021). Secure multiparty computation makes it possible to confidentially analyse PPE data from different parties without any party accessing another's information, except for the final aggregated result. When combined with homomorphic encryption, which allows calculations to be executed on encrypted data, the data remains confidential and safe from both internal and external attacks from end to end of the process (Luterbacher, 2020). The ability to do calculations on data without transferring or decrypting it is crucial for the successful operation of the MSTS. Multiparty homomorphic encryption thus makes it possible to confidentially analyse data at different manufacturers', distributors', or governments' sites (Luterbacher, 2020), providing trust decentralisation and confidentiality protection (Raisaro et al., 2019).

This technology is already in use by systems such as MedCo,[3] Helen,[4] and POSEIDON[5] to guarantee that all the information interchanged between sites is always in encrypted form, including aggregated data. For example, the MedCo system is used for medical research on pathologies such as cancer and infectious diseases by enabling computations of confidential patient data in a hybrid, decentralised manner that overcomes the limitations of a fully centralised or decentralised approach.[6] This software was developed by EPFL's School of Computer and Communication Sciences in collaboration with the Lausanne University Hospital and has recently been deployed at three Swiss hospitals (Luterbacher, 2020).

Under the hybrid MedCo approach, trust is not placed in the security of a single central repository; rather, 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, these SPUs form a secure, federated, and interoperable network wherein only authorised parties can request information as if it were a single unified database. The system allows parties to choose their preferred SPU to reduce maintenance costs. Thus, the hosting of an SPU can be allocated to the parties with sufficient facilities or can be outsourced to another institution for parties with limited resources (Raisaro et al., 2019). 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 (Raisaro et al., 2019). Confidentiality is guaranteed as the keys are collectively encrypted, thus preventing single points of failure and decryption without the cooperation of all SPUs (Raisaro et al., 2019) – none of the SPUs alone, even if compromised, can decrypt the

data stored by it (Raisaro et al., 2019). Therefore, the SPUs are collectively responsible for the security of the data stored and the secure processing of a query by an authorised user (Raisaro et al., 2019).

Additionally, in the MedCo system, only the user issuing the query can decrypt and 'see' the aggregated result, and different levels of access privileges can be provided to different users (Raisaro et al., 2019). In other words, not all users would be able to access the same amount of data. For example, in the context of the MSTS, some users would have access only to very limited data like the aggregated global output of PPE, while others would be able to access more detailed data like production capacity or the available regional PPE inventory.

In sum, the MedCo system can deliver: (1) trust decentralisation, as 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 from tracing 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 try to abuse the querying system (Raisaro et al., 2019). 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 concerns that may prevent companies from sharing their PPE supply information.

Conceivably, MSTS could apply the same software and structure as MedCo at the international level. Each country could have a national SPU which the government, private or public institutions, or non-profit organisations could house and administrate. In this scenario, all parties within the same country could outsource their data to their national SPU, which could combine with other national SPUs to form an international, secure, and distributed network (Raisaro et al., 2019). In addition, we suggest a data minimisation approach to data sharing by manufacturers. This entails collecting the bare minimum needed to calculate an aggregated estimate of PPE supply, which would help soothe the security concerns of distributors and manufacturers. Accordingly, information regarding company identity, such as the company's name, address, or any other identifying information, would not be collected. The only information collected would be current production output, maximum productive capacity, and available inventory of each manufacturer and distributor. Once this information is obtained, multiparty homomorphic encryption would be used to enable secure data flows between MSTS databases at manufacturers', distributors' and/or governments' facilities. This would allow MSTS's algorithms to generate supply-side market information without compromising data confidentiality. In other words, MSTS would not be able to see the data but would be able to aggregate it and produce an encrypted output that only authorised parties would be able to see.

Finally, MSTS could be hosted by research centres at academic institutions with relevant capabilities in cooperation with international organisations such as 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 are part of the Swiss Trust Valley public-private partnership that promotes international digital trust and cybersecurity excellence (The Trust Valley, 2021).

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 deficits relating to the pandemic. These include the COVID-19 vaccine information platform (Hub, 2021) and the WTO's portal on COVID-19 related measures (WTO, 2022). These examples highlight the value of information sharing. Thus, replication of such efforts to improve the transparency of PPE market supply would be especially beneficial for future crisis preparedness.

Considering the above, this article proposes that the MSTS be harboured under the umbrella of the WTO and/or the WHO. Given the imperative need to have government support for the successful implementation of MSTS, the broad membership of the WTO and WHO, and the importance of data for trade efficiency and transparency, we argue that the WTO and the WHO have the institutional capacity and mandate to launch an 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 MSTS:

1. Option A: instal the SPUs in government preferred hosting institutions (e.g. private/public institutions, non-profit organisations, and/or the government itself).
2. Option B: instal the SPUs directly on the premises of public and private companies.
3. Option C: for large firms with sufficient resources, instal the SPUs at their premises; for smaller firms, outsource the SPUs to designated host institutions.

Under any option, all SPUs would communicate with one another to compute and provide aggregated outputs on PPE supply data. We present these three

options for each government to decide which system works best according to its capacities and capabilities. The options offered here are not mutually exclusive: if one government chooses option A and another one option B, the system can still function as effectively.

In addition, we leave 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 and gradually move towards a regional or national level. It is expected that governments' trust in the system will require time, which is hopefully sufficient for the system to become fully operational before the next inevitable pandemic.

On the other hand, it should be mentioned that manufacturers may be tempted to exploit the system. A party could provide misleading information (e.g. reporting only 90 per cent of their actual inventory) to 'cheat' the system and access the aggerate result. However, although we acknowledge this is a possibility 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. To ensure that manufacturers report accurate information and to reward conforming firms, governments could establish domestic mechanisms to review the accuracy of the information collected. In addition, under the WTO framework, participating members could introduce a system of checks and balances (e.g. under the Trade Policy Review Mechanism or through secretariat reports) to detect data inconsistencies.

In addition, we propose that governments introduce financial incentives to induce participation from private firms. For example, manufacturers that commit to sharing information could be favoured with advanced government procurement commitments such as contingency contracts in case of emergency (He et al., 2021). Alternatively, governments could provide other financial incentives to firms that share their information, such as tax deductions, exemptions, exclusions, or credits. These benefits would work to offset the financial gains that some firms obtain during a pandemic from a lack of transparency (e.g. profiting from rising prices). In addition, governments could strengthen regulations to prevent firms from profiting from price gouging and hoarding practices. Regarding the incentives for governments themselves, it is worth highlighting that in democratic countries, the cost of uninformed policy making during a crisis may be losing office in the next election. Considering this, firms sharing their PPE supply information may be in governments' own self interest.

The information produced by MSTS should be open to all members (with different levels of access privileges as mentioned in Section 5.2) to build transparency and preparedness for future crises. The MSTS would allow Members to make informed policy decisions to:

1. Improve preparedness of domestic PPE supply for the next crisis.
2. Contribute to exchanging timely and accurate PPE supply information during a crisis.
3. Promote a coordinated global response to PPE shortages to tackle a crisis more efficiently.
4. Promote coordination among Members to finance the expansion of production capacity of PPE.
5. Promote coordination to pool international buying power to prevent hoarding and bidding wars among Members during a crisis (Evenett, 2020).

Based on countries' responses, MSTS can then be extended to include, for instance, PPE inputs, ventilators, vaccines, and other strategic goods. It is important to stress that this is a pilot proposal 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. To achieve this, the system must remain flexible to promote continuous improvement to suit Members' needs.

6 | 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 strengthen the resilience of global supply chains during crises. As we look ahead and begin to prepare for the next pandemic, public-private cooperation on enhancing transparency will continue to be a critical component of this process, as recognised by the WTO itself (WTO, 2021).

Therefore, this paper seeks to bring attention to and promote public–private collaboration on the need for enhanced PPE supply transparency and encourages governments to 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 MSTS: a secure, public, digital system that aggregates real-time PPE supply data for the benefit of all market actors and policy makers.

A market supply transparency system applied to PPE is politically viable now as it can be launched on a voluntary basis. Therefore, MSTS could function as a pilot initiative to kickstart the future liberalisation of a greater variety of trade related information flows and may be broadened to cover other strategic goods and services with globalised 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 (WTO, 2021), 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 in the face of common threats may remain challenging. Often complacency and competing interests lead to insufficient political support to address major crises (Katz et al., 2018). However, crises ultimately provide signals that an existing order is no longer viable. The global health 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 (Katz et al., 2018; WHO, 2020).

ACKNOWLEDGEMENTS

The authors would like to thank Gabrielle Marceau, Joost Pauwelyn, José Guadalupe Barrera Flores, Majda Petschen, Dayong Yu, Nora Neufeld, Jean-Pierre Hubaux, Michael Kende, Adriana Ontiveros and James Scheibner for helpful comments and discussions. Special thanks to Rashid S. Kaukab for his invaluable insights and support. Special thanks to Dmitry Grozoubinski and Tamara Pironnet, as well as panel participants of the 2021 G2 Hackathon, where an earlier draft was presented. Thanks to Mariana Mendez and Alex Maaza for their contributions during the G2 Hackathon that helped shape this article. All errors are the authors alone. Open Access Funding provided by Institut de Hautes Etudes Internationales et du Developpement within the CSAL-CARE Agreement. [Correction added on 19 July 2022, after first online publication: CSAL funding statement has been added.]

DATA AVAILABILITY STATEMENT

The data that support the findings of this study were derived from the two resources available in the public domain: ITC Trade statistics for international business development (https://www.trademap.org/Index.aspx) and Trading Economics indicators (https://tradingeconomics.com).

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ENDNOTES

[1] Please note that respirators are distinct from ventilators, which are devices that aid a patient in breathing, while the former are masks that protect the wearer. Although ventilators are another strategic good needed as part of pandemic preparedness, they are not included in the scope of this paper due to the differential structure of the ventilator supply chain (Gereffi, 2020). However, the proposal contained herein could be broadened for their future inclusion.

[2] See WCO HS Classification Reference for Covid-19 Medical Supplies 3.01 Edition. Available from: http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/nomenclature/covid_19/hs-classification-reference_edition-3_en.pdf?la=en.

[3] 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 et al., 2019).

[4] A system that allows multiple parties to train a linear model without revealing their data (Zheng et al., 2019).

[5] POSEIDON is a privacy-preserving federated neural network learning (Sav et al., 2021).

[6] The centralised 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 decentralised approach solves the single-point-of-failure issue since it allows parties to enforce local control on their data individually. However, this decentralisation imposes substantial costs on the parties, as they have to maintain an interoperable network (Raisaro et al., 2019).

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How to cite this article: Garcia-Santaolalla, N. & de Klerk, K. (2022) Ensuring Market Supply Transparency for Personal Protective Equipment: Preparing for Future Pandemics. *Global Policy*, 13, 401–411. Available from: https://doi.org/10.1111/1758-5899.13103