

Impacts of Covid-19 on personal protective equipment supply chain: an Italian survey

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Abstract: The Personal Protective Equipment (PPE) supply chain (SC) was seriously affected by disruptions consequent to the spread of Covid-19 pandemic in early 2020, due to the primary role of these products to limit the virus diffusion and the consequent large increase in demand that was experienced. Literature addresses the effects of Covid-19 on the PPE SC of items like masks, visors, and gloves from different perspectives, such as the impacts on vulnerability and the associated need for resilience, the solutions to improve the value chain of these products, as well as the SC performances experienced by the actors involved, particularly the healthcare end users. However, few studies focus on PPE producers and traders operating in the Italian market. The present work discusses a survey aimed at capturing how stock levels, demand rates, and lead times in the PPE SC were impacted by the onset of the pandemic. A questionnaire was administered to a sample of 994 firms selected from the official lists of PPE authorized producers and traders in Italy. The application of the Kruskal-Wallis statistical test highlighted an increase in delivery lead times affecting all the respondents, regardless their SC role. Importers and distributors reported a larger number of customer orders than Italian manufacturers, with consequent higher stock levels, both during and after the first lockdown period. The outcomes of the study might help deepening the causes and effects of the reported criticalities in the PPE SC.

Keywords: Personal Protective Equipment (PPE), Supply Chain, Covid-19, Empirical Analysis.

I. INTRODUCTION

In the first months of 2020 an unknown zoonotic coronavirus, later on named Covid-19, infected human population (Perlman 2020). The initial perception was that it would have been localized in China only but then it spread across the world along with people travelling (Ozili and Arun 2020). Due to the sudden rise in the number of cases and the droplets mode of transmission of the coronavirus, a surge in the demand for Personal Protective Equipment (PPE) was observed globally, in order to protect the population and health professionals, leading to a significant shortage of these key goods (Patel et al. 2017, Shrivastava and Shrivastava 2020). According to EU regulation 425/2016, the PPE function is to protect wearers from health or safety risks coming from the other people. In the context at issue, it acts as a protection between infectious materials and the skin, mouth, nose, and eyes. In particular, the present study focuses on the PPE types most relevant to Covid-19, such as masks, visors, protective glasses, gloves, and gowns. At the pandemic onset, the World Health Organization (WHO) estimated that the healthcare sector would have needed 89 million masks, 76 million gloves, and 1.6 million protective glasses per month to deliver an appropriate response to the COVID-19 globally. Coherently with the WHO forecast, the demand of PPE all over the world grew, in particular during the first pandemic wave, disrupting the global

supply chain (SC) of these goods (Park et al. 2020). China, which is the main PPE producer and exporter (Sharma et al. 2020), was the first country in the world to issue a lockdown period, leading to a shutdown of manufacturing companies and to the introduction of export limitations. At the same time, China also purchased a substantial portion of the existing PPE global supply (Zhu et al. 2020). The relevant decrease of production and export capabilities that, starting from China, affected also the other countries in the world, combined with the Just-in-Time (JIT) approach adopted in recent decades to manage PPE stocks in order to reduce operating costs. Therefore, the already low PPE inventory levels decreased rapidly, as a consequence of the augmented demand, without any possibility of quick replenishment (Gereffi 2020). Furthermore, the Covid-19 related restrictions, such as roadblocks and quarantine measures, caused port congestion and delays in cargo loading/unloading, thus, undermining global SC connectivity of all the products, including PPE and their raw materials (Agostino et al. 2020; Miller et al. 2021).

The existing studies about the impacts of Covid-19 pandemic on the PPE SC address causes and solutions to disruptions by largely focusing on healthcare end users. There is a lack of contributions investigated how and why the main logistics quantities, such as orders, stocks, and lead times, changed in the upstream SC

echelons at the outbreak of the epidemiological emergency. Moreover, few studies focus on Italy, although it was one of the countries mostly affected by Covid-19 (De Maria 2020, Hu 2022).

This work presents an empirical study aimed at identifying the criticalities in the PPE SC during the coronavirus in Italy. To such an end, a questionnaire, directed to PPE producers and traders, is developed. Its purpose is to understand how their daily operations changed during the first pandemic wave, namely March-May 2020, and after it. In particular, the study addresses and explains variations in demand and associated material flows, lead times, and stock levels. The remainder of the paper is structured as follows. The literature background is detailed in Section 2, while Section 3 presents the adopted methodological approach and the questionnaire. Survey results are discussed in Section 4, while Section 5 provides implications and conclusions.

II. LITERATURE REVIEW

The scientific literature dealing with the impacts of Covid-19 on the PPE SC can be divided into three streams: issues in the PPE SC leading to disruptions, related improvement solutions, and surveys to assess how the emergency affected PPE availability, with particular attention to the perspective of healthcare operators.

A. Causes for PPE global supply chain disruptions

The first stream of papers analyses the PPE global SC and the threats caused by the Covid-19 pandemic because of the peculiar characteristics of the products at issue (Miller et al. 2021, Park et al. 2020). Starting from raw materials, the unexpected demand increase led to a shortage in the key PPE components, such as nonwoven polypropylene, a melt-blown fabric, which originated a bottleneck for the whole mask production process (Woolley et al. 2020). As a matter of fact, the need for high quantities of melt-blown fabric required increasing the production capacity in terms of available machines but setting up new production lines usually takes at least half a year. Additionally, China is an important PPE production hub and half of the global supply of masks comes from its manufacturing plants. So when quarantines were first imposed to Chinese workers and then export bans were established also in many other Asian countries, leader in key material exports, the PPE production suffered a severe slowdown (Gereffi 2020, Zhu et al. 2020). With the aim of compensating for the manufacturing shortage, a number of new producers all over the world entered the PPE market right after the Covid-19 outbreak but many of them experienced failures. Such a situation was furtherly exacerbated by roadblocks and other limitations to transportation, as well as by more severe border controls and quarantines incoming products were subjected to in order to contain the virus spread. Cargo flights were mostly suspended and shipping products by means of passenger flights

became a non-viable alternative because these flights were substantially cut during the first pandemic wave. As a consequence, there were congestions and delays that caused disruptions in both raw material and final product supplies, with a significant increase in total SC costs (Zhu et al. 2020). By looking deeper downstream in the PPE SC, the JIT approach was adopted during the last years with the aim of decreasing production, storage, and distribution costs, and based on reduced budgets some key end users, such as healthcare institutions, are subjected to. The sudden unexpected demand increase quickly led to PPE shortages in all the SC echelons (Gereffi 2020). Finally, because of its critical intended purpose, PPE has to meet specific regulations to be sold and used. Therefore, the need for checking regulation compliance, and the related time required, was another bottleneck of PPE massive production and export (Miller et al. 2021).

B. Solutions to improve the PPE supply chain

Following the shortages in the PPE SC, several solutions were put forward by both academicians and practitioners. Some countries strived to adopt centralized strategies to contain the source disruption, also by facilitating manufacturers of nonmedical devices to ramp up production of these goods. There is a number of literature contributions on the topic spanning the main geographical areas in the world. Looking at Europe, an Italian study by De Maria (2020) addresses the national management of PPE and the preparedness plan to avoid future disruptions similar to the one occurring to this sector in the first period of the Covid-19 pandemic. Moving to the US, Cohen and Rodgers (2020) first identify the four contributing factors to shortages, namely the way hospitals budget for PPE, domestic demand shocks, federal government failures, and the global SC disruption. Then the authors suggest improving the capacity of both federal and local governments to stock and distribute PPE, developing specific regulations about the correct use of these products, and decreasing the US dependence on imports. Finally, about Asia, the Chinese government introduced special measures to foster an increase in mask production. In particular, subsidies were offered to manufacturers for raw material purchase and workforce hiring. Similarly, the Japanese government largely supported companies to increase their capital investment in mask production, as well as guaranteed the supply of more than 600 million masks per month in 2020 (Park et al. 2020). The research on the present stream also provides more general, non-country specific, studies. Recommendations on PPE SC design are given by Sharma et al. (2020). They suggest conducting stress tests based not only on cost, quality, and delivery performance measures but also on resilience, responsiveness, and re-configurability capabilities. The crucial role of stress testing to ensure a quick ramp up of PPE domestic production is also recognized by Dai et al. (2020). Additionally, with the aim of mitigating supply risks, besides keeping an adequate stock level, companies should rely on multiple suppliers of strategic

components located in different geographical regions, with the possibility to activate alternative sources on short notice (Harvey 2020). Sales and Operations Planning is a SC area that should be carefully considered. PPE orders, distribution, and monitoring of their use should be centralized to allow improved demand forecasts, together with increasing stock visibility, and information sharing among SC echelons (Dai et al. 2021).

C. Empirical studies about the effects of Covid-19 on the PPE supply chain

By closely looking at the topic of the present research, some literature contributions discuss surveys on how healthcare users dealt with PPE shortages. The Royal College of Surgeons of England investigated how surgical personnel reacted to the lack of PPE in the first pandemic phases. One third of the respondents affirmed that PPE supply and management at their trusts were not adequate to make them able to do their job in safe conditions and more than half reported PPE shortages at their organizations (Rimmer 2020). By taking an international perspective, a questionnaire was administered to healthcare professionals with the aim of knowing the availability and use of PPE in the treatment of patients with Covid-19 in intensive care units (ICUs). Again, respondents highlighted a widespread lack of PPE and a consequent need for reusing single-use items (Tabah et al. 2020). Similar findings were achieved by another survey assessing PPE availability across ICUs in six Asia-Pacific countries (Rajamani et al. 2021). Despite a good awareness of WHO guidelines about PPE conformity, their supply was highly compromised in the considered countries, often forcing to use poor quality equipment. The point of view of upstream SC echelons is considered by Hu (2022), who conducted interviews to sales and export managers of B2B companies in Italy. Her aim is investigating the use of digital technologies and social media to cope with the PPE disruption during the first pandemic wave.

D. Motivation and objective of the work

The performed literature review reveals that, although the topic is relatively new, there is already a significant number of studies exploring the negative implications of Covid-19 on the PPE SC and possible countermeasures. However, the specific impacts on the key logistics aspects for companies positioned in different upstream echelons are still scarcely investigated. In fact, the focus is usually on end users, especially healthcare ones. Also, very few published literature consider the Italian situation, although this was one of the international countries most affected by the first Covid-19 pandemic wave.

The present work discusses a survey aimed at analysing how the onset of the pandemic changed the main PPE SC variables, such as stock levels, demand rates, and lead times, for Italian producers, importers, and distributors. The reasons for such changes are explained to suggest interpretations useful to deepen the knowledge about the causes for the shortages and delays

in PPE supply that brought severe consequences on public health.

III. METHODOLOGY

The survey has been conducted through the following steps.

Sample identification. Companies involved in producing, importing, and distributing PPE operating in Italy are considered for the present study. To this end, national and regional databases of authorized producers and sellers are checked, e.g. lists of companies authorized to sell PPE by the Italian institute for work accidents (INAIL), companies that received economic incentives to expand or convert their production to PPE according to the Law Decree n. 18 on March 17th, 2020, named “Cura Italia” Decree, and lists of companies authorized to produce PPE during the pandemic by the healthcare national institute (Istituto Superiore di Sanità). A total number of 994 companies are thus selected.

Questionnaire construction. The main PPE SC variables recognized by literature as the most affected by Covid-19 are identified. Based on that, a questionnaire is structured including the following topics: supply lead times, inventory levels and management policies, number of orders and associated quantities, number of order lines, and customer location (Gereffi 2020, Harvey 2020, Park et al. 2020). Specific questions are posed to observe the changes in the key SC quantities both during the Covid-19 onset and after this first pandemic period. Each change is assessed compared to the 2019 situation. Survey questions are differentiated depending on the respondent category. For all the questions, except for those about inventory levels and lead times, the possible answers are scored through a Likert scale ranging from 1 (no relevant change in the assessed SC variable) to 7 (extremely significant change). Then, for each of these questions the respondents are asked to also state the nature of the assessed change, either increase or decrease in the value of the related variable. The average stock level is assessed by a Likert scale defined as follows: 1 (unchanged), 2 (limited increase), 3 (moderate increase), 4 (significant increase), 5 (extremely significant increase). Finally, the lead time variable is scored by a Likert scale ranging from 1 (< 5 days) to 5 (> 15 days). The questionnaire has been first administered to a test group composed by academic SC experts, and, based on the test outcomes, it has been refined in order to obtain the most reliable results.

Questionnaire administration. The questionnaire is implemented by means of Google Form and subsequently sent to the sample companies by e-mail. The administration period started on November 25th, 2020, and lasted until the end of January 2021. Up to three reminders to complete the questionnaire were sent to the surveyed companies. 94 companies over the 994 contacted ones completed the survey, with a response rate of 9.5%. This can be considered a good result, as double-digit response rates are increasingly difficult to

achieve (Harzing et al. 2013). Survey responses are registered in an Excel spreadsheet in order to create a dataset to be used in the subsequent analysis.

Questionnaire outcomes analysis and interpretation. The data collected through the questionnaire are analysed by means of both descriptive statistics, useful to identify the main characteristics of respondent companies, and a quantitative statistical technique. Since the collected data are not normally distributed and Likert scales are ordinal in nature, and so the distance between two consecutive scores cannot be considered always the same, a non-parametric test is used. The ultimate aim of the present research is understanding if different categories of players in the PPE sector reported similar changes in the main SC variables. Therefore, the Kruskal-Wallis test is selected because it inspects whether the populations have identical medians, which means that samples originate from the same distribution. If the test has a p-value lower than the significant threshold, usually set to 5%, the null hypothesis that populations have identical medians is rejected and the alternative hypothesis, namely that there is at least one different median value among the groups, can be considered true (Arditi et al. 2015). Two categorical variables are identified as interesting: the SC role and the main geographical area served by the surveyed companies. For each of the two categories, a Kruskal-Wallis test is completed through the Minitab statistical software. Outcomes of the test are then interpreted based on literature.

IV. FINDINGS

The 94 valid responses provide quite a complete picture of the companies operating in the Italian PPE market. Most of the respondents are small and medium enterprises, with 54% of them constituted by companies with a yearly revenue less than 2 M€. This is in line with the average size of the companies in the PPE sector

in Italy. Additionally, Figure 1 shows that the respondents are quite active in the global PPE market. In fact, although 52% of them operate in the Italian market only, the remaining 48% also serves international customers located in Europe, US, China, and worldwide. Such an outcome enables to include in the empirical analysis the effects of Covid-19 on PPE SCs in heterogeneous countries. About the SC roles of the respondents, there is a balance between Producers (52%) and Traders (48%), the latter being constituted by 31% of companies whose main activity is importing PPE and 17% of firms mostly active in distributing such products to retail stores. These percentages enable to uncover SC criticalities associated with not only producing PPE but also distributing it.

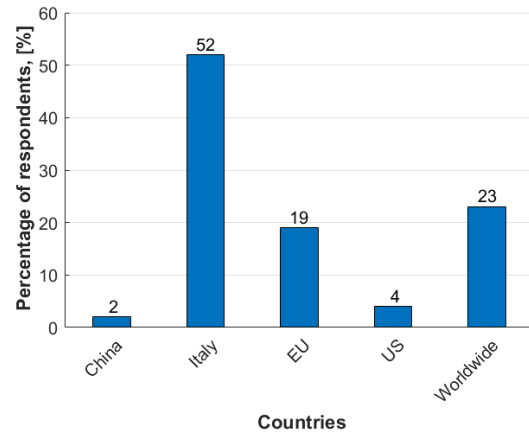


Fig. 1. Distribution of respondents according to served countries

Table 1 details the results of the Kruskal-Wallis test performed on the different SC roles in the sample. The Italian lockdown period referred to is the first and most severe one, from March 9th until May 4th, 2020.

TABLE I
KRUSKAL-WALLIS TEST ABOUT SC ROLES

VARIABLES (* means an increase in the associated variable)	Mean scores			p-value
	Producers	Importers	Distributors	
<i>Change in n. customer orders during lockdown (*)</i>	3.00	3.50	4.00	0.57
<i>Change in n. customer orders after lockdown (*)</i>	2.00	4.00	5.00	0.05
<i>Change in quantities shipped during lockdown (*)</i>	3.00	5.00	4.00	0.24
<i>Change in quantities shipped after lockdown (*)</i>	2.00	4.00	4.00	0.02
<i>Change in n. outgoing order lines during lockdown (*)</i>	2.00	5.00	3.50	0.08
<i>Change in n. outgoing order lines after lockdown (*)</i>	1.50	4.00	4.00	0.00
<i>Delivery lead time during lockdown</i>	2.00	3.00	2.00	0.24
<i>Delivery lead time after lockdown</i>	1.00	1.00	1.00	0.40
<i>Average stock level during lockdown</i>	2.00	3.50	3.00	0.45
<i>Average stock level after lockdown</i>	2.00	3.00	3.00	0.80
<i>Change in n. supplier orders during lockdown (*)</i>	3.00	3.50	3.00	0.31
<i>Change in n. supplier orders after lockdown (*)</i>	2.50	3.50	4.00	0.00
<i>Supplier lead time during lockdown</i>	1.00	3.00	3.00	0.01

Producers, Importers, and Distributors all reported a moderate to significant increase in customer orders, as well as the associated quantities and order lines shipped, during the lockdown period. However, Importers and Distributors had to address a larger order increase than Producers, especially after the lockdown. This is due to the fact that several manufacturing companies entered the PPE market following the diffusion of the Covid-19 pandemic. Thus, they had to wait some time before starting their operations in order to acquire and set the necessary production equipment. Also, small to medium enterprises applied to benefit from Italian Government subsidies. The “Cura Italia” Decree allocated 50 M€ to support Italian firms willing to expand and reconvert their business to produce PPE against Covid-19 and companies started to receive these funds in April 2020. On the contrary, Importers and Distributors could guarantee a larger PPE supply already in the final weeks of the lockdown period, once disruptions were overcome, by relying on foreign manufacturers, although the quite long supplier lead time they experienced (Agostino et al. 2020). This is the reason why Importers and Distributors reported a higher change in supplier orders after the lockdown, in order to fulfil the increased demand of their customers. Additionally, unlike Producers, Importers and Distributors did not have to convert their business structure to react to market changes. About the delivery lead time values, no statistically significant differences can be observed among Producers, Importers, and Distributors, but they were on average longer in the lockdown period than after it, when transportation blocks were relaxed. Finally, the average stock levels of all the three SC echelons increased both during and after the lockdown period, with slightly high values for

Importers and Distributors who had to balance the JIT approach they applied before the pandemic with the need to build stock to be responsive towards their customers (Barber et al. 2020). Table 2 shows the Kruskal-Wallis test outcomes by addressing the different geographical areas served by the surveyed companies. By focusing on the lockdown period, the increase in the number of customer orders, quantities shipped, and outgoing order lines was larger for those companies whose customers are located in China and worldwide than for the companies with customers limited to Italy, EU, and US. If during the first weeks of the lockdown period, the countries most needing PPE were the Asian ones, and mainly China, later on the number of cases increased also in Europe and Italy. In fact, after the lockdown the three variables at issue report a growth in their mean scores for Italy and EU, while they decreased for China. The epidemiological situation in China was slowing down after May 2020, while, after an improvement during the summer period, the Covid-19 infection progressively increased in Europe and reached a worrying status in winter (Lupu and Tiganasu 2022). Furthermore, once overcome national lockdown periods, Chinese PPE manufacturers resumed their activities and the need for importing items from abroad decreased. A different situation characterizes the US market: the three variables at issue basically stay unchanged during and after the lockdown. Such a result might be due to a different epidemiological trend: the number of reported cases as of May 1st, 2020, was equal about to 30,000 (James et al. 2022), pretty lower compared to the total US population. Additionally, European and Italian export bans might explain the statistical evidence.

TABLE II
KRUSKAL-WALLIS TEST ABOUT MAIN GEOGRAPHICAL AREAS

VARIABLES (* means an increase in the associated variable)	Mean scores					p-value
	China	Italy	EU	US	Worldwide	
<i>Change in n. customer orders during lockdown (*)</i>	3.00	2.50	1.50	1.00	4.00	0.02
<i>Change in n. customer orders after lockdown (*)</i>	2.50	3.00	3.00	1.00	4.00	0.29
<i>Change in quantities shipped during lockdown (*)</i>	6.00	2.00	1.50	1.00	4.00	0.02
<i>Change in quantities shipped after lockdown (*)</i>	4.50	3.00	3.00	1.00	3.00	0.22
<i>Change in n. order lines during lockdown (*)</i>	6.00	2.00	1.50	1.00	4.00	0.05
<i>Change in n. order lines after lockdown (*)</i>	4.50	3.00	3.00	1.00	3.00	0.38

V. DISCUSSION AND CONCLUSIONS

The present work provides an overview on the status of the PPE SC in Italy as a consequence of the Covid-19 pandemic, especially in its first phases. The changes in the main logistics quantities during and after the March-May 2020 lockdown period have been compared and interpreted. The outcomes of the survey are useful to increase the knowledge about the criticalities suffered by the Italian PPE industry, in order to understand the weak points of the adopted strategies and to improve the resilience to future similar shortages. Although in a limited way, the reaction of the sector at issue to the pandemic emergency in this country has been already investigated in literature (Hu 2022), but without focusing on the behaviour of individual SC echelons. Moreover, the general literature on the PPE SC mainly addresses the final effects of product shortages and delays on end-users. In particular, great attention has been paid to healthcare professionals (Rimmer 2020, Tabah et al. 2020), who largely suffered the consequences of the lack of appropriate PPE, in some cases also losing their lives. This is very true for Italy, which reported high death rate among frontline healthcare workers (Ranney et al. 2020). Such an evidence poses a need to explore the root causes back in the value chain of the compromised service level that was experienced.

The research proposed in this paper has implications for both researchers and practitioners. From an academic point of view, the survey results might foster vertical studies that deepen the challenges faced by each single SC echelon. In such a context, it would be interesting also to explore to what extent the SC structure was able to recover from unexpected demand shocks. One research field that might benefit from the results of this study is SC risk management (Cagliano et al. 2021). First, investigations can be carried out to assess whether the supplier network of the companies in the PPE industry was enough large and heterogeneous to mitigate the risks associated with an interruption in sourcing strategic materials. Additionally, the survey outcomes might inspire the development of risk management methodologies and contingency plans able to deal with events affecting SCs of key products that are characterized by a low probability of occurrence but extremely relevant impacts. The interpretation of the questionnaire results can support practitioners in having a more comprehensive understanding of the events that affected their SCs in the first Covid-19 periods, other than what happened to their firms. This can provide them a better knowledge on the main issues that affected their partners, not only in their same SC tier but also in the other ones.

However, the work suffers from some limitations. First, the study has been carried out over all the PPE types considered, without analysing each single product category. Moreover, the survey was intended for only one nation, namely Italy, without addressing the criticalities that affected PPE SCs abroad. Also, the

study is limited to the first national lockdown and the following time period.

Therefore, future research efforts will be directed towards developing empirical analysis involving multiple countries aimed to compare the achieved results. First, this will allow to determine any differences in demand and stock management strategies adopted worldwide. Second, it will assist in assessing the role of the geographical location of the supply base in mitigating SC disruptions. Finally, the empirical analysis will be extended to the next pandemic waves that occurred overtime in order to discover any trends in SC behaviour, also considering the peculiar characteristics of each PPE type.

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