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Citation: Sodhi, M. & Tang, C.S. (2021). Supply Chain Management for Extreme Conditions: Research Opportunities. *Journal of Supply Chain Management*, 57(1), pp. 7-16. doi: 10.1111/jscm.12255

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Permanent repository link: <https://openaccess.city.ac.uk/id/eprint/25307/>

Link to published version: <https://doi.org/10.1111/jscm.12255>

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Supply Chain Management for Extreme Conditions: Research Opportunities

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Abstract: Large companies were concerned about their supply chains with environmental and social sustainability and disruption from natural disasters, conflict, and trade disagreements even before the advent of Covid-19. The additional challenges presented by Covid-19 in 2020 are “extreme” in being distinct from supply chain risk in that not just particular companies, but also entire societies are affected. Therefore, it is appropriate to rethink supply chain management (SCM) for research and practice to cope with extreme conditions, now and in the future, whether due to pandemics, war, climate change, or biodiversity collapse. In this essay, we first present the widespread challenges, along with some of the responses. We then list research opportunities for supply chain management in extreme conditions. These opportunities pertain to retailers’ survival in the face of highly successful e-commerce giants and the mixed use of robots and human workers. There are also opportunities to share supply-chain capacity in distribution and coopetition regarding medically necessary items such as anti-virals or vaccines. The growing role of government in supporting business, including the creation of industry commons, also presents avenues for further research.

Keywords: General management issues; electronic commerce; partnering

INTRODUCTION

Disruptions caused by the Covid-19 pandemic and ongoing geopolitical tensions are threatening to upend global supply chains. The Covid-19 virus has created a worldwide public health crisis and plunged much of the world into an economic crisis. The IMF revised its earlier forecast of 2020 from 3.3% global growth to a 3% contraction in its April'20 prediction and, again, to a 4.9% contraction in its June'20 forecast. At the same time, prolonged shortages of medical equipment exposed the vulnerabilities of supply chains and affected worker safety and health at the workplace. Efforts to stem the spread of Covid-19 with lockdowns also created widespread unemployment in many countries, affecting overall demand from consumers and supply, including those of medically essential goods.

Covid-19 only added to the geopolitical supply chain risks from 2019 and earlier. Proposed trade-war- and geo-politics-motivated simplistic solutions had already triggered companies to consider selective reshoring of some of their manufacturing operations. The pandemic further stoked fears in the US about having lost too much critical manufacturing capacity to China because a significant proportion of antibiotics, painkillers, active pharmaceutical ingredients, and personal protective equipment are manufactured in China. Even with US President Trump imposing tariffs on some Chinese goods and threatening more, US presidential candidate and former Vice-President Joseph Biden further proposed shifting production of a range of critical products back to US soil (Biden-Harris 2020). Actual reshoring has not followed the rhetoric, though. Bringing production back to the country is more complicated than anticipated. For instance, government efforts to create a reusable gown for protection against Covid-19 in the UK had not succeeded even towards the end of 2020 (FT, 2020a). At the same time, geopolitical risk creates uncertainties for companies.

The year 2020 also saw usually high temperatures in the Arctic leading to carbon release, continuing mass migration, and intensification of geopolitical tension among large economies: between the US and China, India and China, and the UK and the EU. Such conditions may well prevail again in the future – for instance, the impact of natural disasters is growing exponentially as a trend by some metrics (Sodhi, 2016), possibly tied to climate change.

These conditions are *extreme* in that they go beyond a supply chain risk incident affecting a limited number of companies for a short period. Even the 2010 volcano eruption in Iceland, which involved many travellers and disrupted many supply chains, disrupted air travel for only two weeks. By contrast, Covid-19-related disruption is global and may continue beyond the calendar year 2020 to 2021 and even beyond. Due to the risk associated with future pandemics, climate change, and geopolitics, there is a need for companies and researchers to rethink how to manage supply chains in

such extreme conditions. Although the supply chain risk literature goes back to the early 2000s, the approaches are not enough to cope with the extreme conditions we see at the time of this writing. Therefore, it is worthwhile to rethink both supply chain management for extreme conditions, going beyond supply chain risk management.

In this essay, we first frame the supply-chain challenges wrought by Covid-19 and geopolitics along different dimensions. Then we consider the responses by companies and governments, including those enabled by new technologies. Finally, we present some research opportunities for supply chain management for extreme conditions.

COVID-19-RELATED AND OTHER SUPPLY-CHAIN CHALLENGES

Covid-19 has affected many countries. Many countries, including the US and much of Europe, have experienced two peaks of new cases in 2020. By late October, there were over 42 million cases reported, and over 1.1 million fatalities. Melbourne in Australia, Leicester in the UK, and Bengaluru in India went under lockdown twice. We view dealing with these extreme conditions – spread over time and across the globe – for supply chains as going well beyond supply chain risk management. When the shocks in supply or demand – or both – are so big that the impact is spread from a few companies or a section of society to most companies and much of society, we need *extreme supply chain management* (Figure 1).

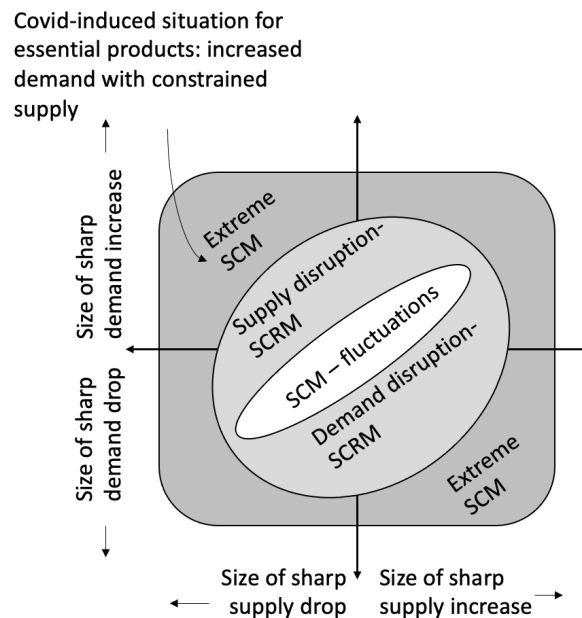


Figure 1: A depiction of the scope for supply chain management (SCM), supply chain risk management (SCRM), and extreme SCM in terms of the sizes of simultaneous demand and supply shocks

Extreme conditions disrupt supply chains along multiple dimensions simultaneously. These dimensions are what we assume for ‘normal’ supply chain management:

Demand certainty. Supply chains can be efficient or effective when demand is stable and predictable. As of this writing, vaccines for Covid-19 are not available, but demand would be hard to predict when they are. It is unclear if any of the vaccines under development will be effective against a mutating virus and when many people are either skeptical or reluctant to be vaccinated (Dai and Tang, 2020b; Cornwall, 2020). Moreover, there is an unprecedented shift in demand across existing channels for various products during the pandemic. For instance, due to work-from-home, demand for toilet paper has shifted from commercial type to home-use type. Home delivery services via e-commerce have also grown multifold in 2020 (Terlep and Gasparro, 2020). Different channels serve the commercial and residential demands with supply chains already optimized for those channels, so the shift in the market means demand uncertainty for both channels even if the total demand is stable.

Supply certainty. SCM assumes a reliable supply for the most part. However, companies can face a highly uncertain supply caused by pandemics, geopolitics, and human-made or natural disasters. Besides COVID-related disruptions, global tensions – whether due to trade or security – or environmental and social governance (ESG) pressures may cut off supply sources. The growing use of sanctions also impacts supply, especially from China (Loh and Tang, 2020).

Channel stability. Supply chain channels are assumed to be stable and reliable. However, Covid-19 has disrupted traditional channels like retail channels due to lockdown, and demand has shifted to e-commerce channels. Deloitte (2020) reported that the shift to online channels is likely to be sticky, even after the pandemic, thus impacting brick-and-mortar stores for the long term. Amazon and other e-commerce companies have benefited, while pure brick-and-mortar retailers have suffered a loss of sales (Kilgore, 2020).

Availability of labor. Capacity is assumed to be another constant, and the availability of labor is part of this assumption. However, Covid-19 has resulted in companies facing inadequate and unplanned labor unavailability. For example, coronavirus outbreaks in the workforce have created uncertain temporary closure of US meat processing plants (Telford, 2020). As of July 2020, the number of new Covid-19 cases started climbing up again in many countries, creating uncertainty about reopening businesses, public transportation, and schools. Lockdown and quarantine procedures have significantly disrupted operations in countries and sectors that depend on seasonal labor from other countries.

Supply chain visibility. In normal SCM, we know (or should know) who the suppliers are. Covid-19 caused severe concerns about the provenance of some critically needed goods. Although the Food

and Drug Administration (FDA) knows that 13% of brand and generic API (Active Pharmaceutical Ingredient) manufacturers in China, it does not know the actual volume of Chinese APIs in the US market. Dai and Tang (2020a) reported that over 1,300 Chinese medical suppliers, including 217 N95 mask manufacturers, used false addresses and nonworking numbers in their registrations with the FDA. Lack of visibility creates uncertainty of quantity and quality of supplies in the near term and uncertainty of availability in the long term. As more firms adopt blockchain technology, concerns over traceability will reduce (Sodhi and Tang, 2019), but conditions being as they are in 2020, it is hard to implement such new technologies.

Geopolitical stability. One determinant of supply stability in a global world is geopolitical stability. However, geopolitical risk was increasing even before Covid-19 showed up. And one legacy of Covid-19 will be that many countries will seek to manufacture more medical equipment within the state. Climate change deteriorates not just international shipping routes but also political conditions, thus providing a reason for shortening supply chains. Besides, there is a growing political conflict between significant trading economies. For instance, triggered by India and China's skirmish in mid-2020, India imposed additional scrutiny of imports of electronics components from China, disrupting Foxconn's production of Apple iPhones in India (Kalra, 2020). Despite the US and China being major trading partners, their recent trade conflict has extended to technology, whether for 'security' or 'strategic rivalry.' The US government has limited Huawei and its suppliers' access to American technology and software, disrupting Huawei's 5G equipment development (Loh and Tang, 2020). Given the tensions between China and the US (and Australia, the EU, India, and the UK) and human rights concerns, global supply chains emerging from China for western consumers look less stable for the coming years (Pamuk, 2020).

Permanent nature of supply chains. Supply chain management assumes supply chain operations are for an extended period. However, similar to humanitarian project-based supply chains, Covid-19 has necessitated creating such *project-based supply chains*. For instance, in the US and the UK, such temporary supply chains came into existence for ventilators and PPE suits but did not work well as regards meeting the demand for the specified production. Misspecification of products, the uncertainty of demand, and the inability to supply challenged these project supply chains. For instance, UK-based manufacturer Dyson developed a ventilator in response to the government's urgent call and found its product would not be used after all only when it neared shipment (FT, 2020b). As scientists predicted that future pandemics would occur more frequently than rare 100-year events, the supply chain's permanent nature is now questioned (Schmidt and Undark, 2020).

Reliability of financial flows in supply chains. The normal functioning of supply chains needs reliable financial flows; otherwise, we get into the situation seen in the 2008-09 financial crisis that

disrupted many supply chains. Due to prolonged closures of stores globally during Covid-19 and unprecedented job losses, consumers curtailed their spending, and sales of all unessential products fell. Consequently, Deutsche Bank downgraded companies like auto-maker GM that had only 15 weeks of liquidity left at one time. Auto manufacturers such as Honda, Jaguar, and Volkswagen have financial difficulties, and retailers such as Neiman Marcus Group Inc. and J.C. Penny have filed for bankruptcy. Airlines such as British Airways and hotels such as Marriott initiated massive layoffs. Under such conditions, many manufacturers will be likely to suspend or postpone paying their suppliers. Buyers have canceled orders with suppliers to cut costs and also delayed or defaulted on existing invoices. These delays or defaults affect suppliers who are stuck with materials or components no longer needed. These suppliers have no funds to pay their suppliers in turn, creating a vicious cascade. As countries plan their strategies to loosen or exit the current lockdown, many sectors will be entering a recovery stage. Without financial support, liquidity-drained suppliers may be unable to ramp up production quickly, delaying the recovery of supply chain operations from the current crisis (Tang and Yang, 2020).

CURRENT SUPPLY CHAIN RESPONSES TO CHALLENGES

Companies facing extreme challenges caused by the pandemic are rethinking their supply chain operations. Governments in many developed countries are stepping up to help with fiscal, monetary, and industrial support. For instance, as already mentioned, both US and UK governments encouraged developing temporary supply chains for PPE and ventilators. Below are some examples of different responses that many companies and governments have taken along the various dimensions outlined above:

Traditional solutions to manage supply and demand uncertainty. Building reserves of inventory to cover uncertain supply and uncertain lead time, and pooling to dampen fluctuations are some of the traditional solutions employed by governments and companies against Covid. There are also ways to make the capacity more flexible or use outsourcing with redundant suppliers to get the same effect (Chopra and Sodhi, 2004). For example, Georgia-Pacific (manufacturer of Sparkle paper towels) increased its production capacity by reducing product variety (two-ply, three-ply, number of sheets per roll, and the number of rolls per package). They reduced changeover time and increasing production to meet more demand (Terlep and Gasparro, 2020).

Coopetition by creating complementary products and sharing resources. Competitors typically do not share supply-chain resources. However, when dealing with extreme conditions with uncertain supply and uncertain demand, sharing resources with competitors allows for greater efficiency for all companies. For instance, companies can share e-commerce delivery and storage resources. Also, two

global pharma rivals, GSK and Sanofi SA, have sought to develop complementary products by agreeing to create a vaccine for mid-2021 release using Sanofi's antigen against Covid-19 and GSK's vaccine booster against pandemics in general (Reuters, 2020a).

Creating temporary channels. Before Covid-19, food banks in the US could deliver food in carts (big boxes) to allow beneficiaries to pick their preferred items. However, to comply with health safety guidelines during the pandemic (masks, gloves, and social distancing), the food banks needed to pre-pack an assortment of items into small boxes so that each beneficiary can grab a pack and go. Due to demand surge and churches' closure, food banks have coordinated with different agencies to deliver foods in makeshift locations such as parking lots, pop-up tents, and public schools (Food Bank, 2020). Many retailers found that online sales were the only way to sell under lockdown – the retailers with an existing omnichannel approach were fine. Still, the others had to develop new channels from scratch to enable online orders or curbside (also, kerbside) pickup.

Financial intervention from the government. Supply chain participants seek profits, so governments in many countries have provided direct subsidies or tax credits to incentivize these companies to maximize social welfare. In the UK, the government-subsidized food in restaurants by 50% during weekdays to encourage consumers to start coming back to these businesses after lockdown. In the US, the USDA launched the \$19 billion Coronavirus Food Assistance Program (CFAP) in April 2020 to help farmers and ranchers stay afloat and sustain demand for agricultural products. The CFAP program sought to provide \$16 billion to support farmers and ranchers to continue their production. The USDA also brought in the Farmers-to-Families Feedbox program (USDA, 2020) to fill food donations' shortfall to over 200 food banks. It earmarked \$3 billion to purchase fresh produce, dairy, and meat directly from the farmers to distribute to food banks in different states under the “Farmers to Families Food Box” program (USDA, 2020). The FDA launched the \$10 billion federally funded “Operation Warp Speed” (HHS, 2020) as a public-private partnership with competing pharmaceutical companies to ensure the delivery of 300 million doses of safe and effective vaccines delivered by January 2021 (Dai and Tang, 2020b). However, there are questions about the timeline being unrealistic and duplicating funding provided to these companies.

Using online platforms to match supply and demand. Since April, the breakdown of traditional distribution channels and uncertain supply from conventional sources has left healthcare workers pleading for PPE. In response, volunteers created different online platforms, for instance, getusppe.org in the United States and Covidppehelp.ca in Canada, to ask people to donate PPE to designated health care organizations. Besides PPE, lots of produce destined for restaurants was wasted during Covid-19, even though the demand for food assistance at food banks has skyrocketed. To reduce food waste, a group of students from universities on the east coast of the US developed a

crowdfunding online platform FarmLink (thefarmlinkproject.org), to acquire surplus produce from farms and pay transportation costs to deliver fresh food to food banks.

They were using online platforms to collaborate across different supply chains. Collaboration across firms in various sectors can be mutually beneficial. For example, during the Covid-19 lockdown, Amazon, CVS, and Albertsons faced a demand surge, while Hilton hotels were under lockdown. By collaborating with Hilton, these retailers could hire furloughed Hilton workers for short-term assignments (Rivera 2020). Similarly, when Hema (Alibaba's retail grocery chain) faced demand surges and labor shortages during the Covid-19 pandemic, it connected with restaurant chains such as Xibei and Yunhaiyao via an online platform to develop an employee-sharing plan. Thus, over 3,000 restaurant workers could temporarily help Hema without permanently losing their jobs (Wang 2020).

Leveraging just-in-time supply-chain financing to financial reliability. The financial flow in supply chains fuels global trade. However, banks are reluctant to offer loans to small and medium-sized suppliers without supply chain visibility, especially in developing countries. A Chinese fintech startup, JDH, used mobile technology and blockchain to allow lenders to finance suppliers several tiers deep in electronics manufacturing supply chains. Such an approach alleviates potential supply liquidity-related disruption caused by suppliers further upstream in the supply chain. Also, fintech lenders such as Ant Financial (formerly Alipay, affiliated with Alibaba) and Kabbage (a US-based online financial technology company) can approve business loans within minutes by using artificial intelligence. Increasing the lending frequency with smaller amounts and shorter delays enables lenders to reduce risk while better serving supply chain partners with just-in-time lending (Tang and Yang, 2020). Buying firms also have an interest in ensuring that a supplier does not fail due to financial distress (Bode, et al. 2014).

Initial efforts on track-and-trace technologies for visibility in the supply chain. Technologies such as IoT, sensors, blockchain, and advanced robotics associated with Industry 4.0 are becoming more affordable and accessible. In the future, blockchain can enable firms to track-and-trace products along the supply chain, an example being Walmart and IBM trials using blockchain to authenticate pharmaceutical products (Tang and Veelenturf, 2020). Track-and-trace technology is also being tested in many countries as of this writing, although with mixed results. Track-and-trace technologies for Covid infections are being tested in many countries as of this writing, although with mixed results.

While the above responses have been largely useful, these are also inadequate to enable recovery of supply chains back to where they were before the Covid-led supply and demand shocks, positive or negative. Extreme circumstances like the ones we find today worldwide require more, including supply chain researchers' effort. We outline some research opportunities next.

RESEARCH OPPORTUNITIES IN EXTREME SUPPLY CHAIN MANAGEMENT

Over the years, the SCM literature has gone from centralized control to decentralized situations, from deterministic to stochastic demand (and supply), and from profit-maximizing to triple-bottom line-oriented supply chains. Research in supply chain management (not including purchasing and supply management) over the last three decades can be summarized as follows (Tang 2006):

- Managing centralized supply chains with vertically integrated firms with deterministic or stochastic demand with centralized control (e.g., Cohen and Lee, 1988),
- Managing decentralized supply chains, contracts, and coordination (Cachon 2003), and the bullwhip effect (Lee et al. 1997) and the OM research community has examined different coordination issues using game-theoretic model and supply contract theory (Sahin and Robinson, 2002), and more recently, digitalization (Sweeney et al., 2020)
- Managing risk in supply chains with disruptions caused by human-made/ natural disasters, uncertain supply, or uncertain demand (e.g., Sodhi and Tang, 2012; Manhart et al. 2020),
- Managing humanitarian supply chains to save lives and support beneficiaries after a disaster with supply chains created on short notice using prepositioned inventory or cash (Van Wassenhove, 2006; Quarshie and Leuschner, 2020), and
- Managing environmental and social sustainability in supply chains (Busse, 2016), with the growing interest in social responsibility (Lee and Tang, 2018) and subsidies from donors or governments (Yu et al. 2020).

As we saw from the above responses, efforts – and existing research – can help with the challenges along any of the individual dimensions that we listed earlier: (1) demand certainty; (2) supply certainty; (3). channel stability; (4) labor and office staff availability; (5) visibility into provenance and order status; (6) geopolitical stability and free trade; (7) permanence of supply chains; and (8) stable financial flows in supply chains. However, the challenge we face with Covid is along all of these dimensions simultaneously, leaving little room to fall back on other resources while one – say, availability of staff – is compromised. Covid-19 has proved we need more than what the existing literature provides when it comes to extreme conditions. Therefore, we can outline some research opportunities for supply chain management to tackle extreme situations like the one the pandemic has created:

Smaller retailers competing with online e-commerce giants or platforms. During the Covid-19 Pandemic, sales on online e-commerce platforms such as Amazon and Alibaba's Taobao have grown

substantially. Many smaller merchants have had to sell their products on these platforms, especially during lockdown. While Amazon gains substantially, the value created for a small business selling on Amazon is unclear. The competition among small businesses selling on Amazon becomes fierce because consumers can compare their prices. Also, consumers can compare their prices with similar products from Amazon's private label products. This conflict raises the following research questions after Covid-19:

Q1. How should these third-party sellers (small businesses) compete on e-commerce platforms when they all have the same resources for market reach and delivery?

Q2. How can e-commerce platforms help these third-party sellers to sustain their operations?

Automation vs. human labor. Even before Covid-19, there were concerns about how automation can replace human labor. During Covid-19 Pandemic, it has pushed faster adoption of automation to reduce contamination, improve worker safety, and reduce uncertain labor force due to the next outbreak. For example, Tyson, the biggest US meat company, is shifting from human meat cutters to robotic butchers and using advanced robotics to debone chickens (Bunge and Newman, 2020). In the same vein, Italian auto-maker Ferrari wants to introduce more advanced robotics on the factory floor to keep assembly workers farther from each other for safety. Increasing automation poses the following research questions:

Q3. What is the impact of a hybrid system (robotics and human labor) on productivity and quality?

Q4. With fewer interactions among workers, how would this affect their job satisfaction?

Cooperation with competitors. We used Covid-19 vaccine development as an example to motivate the notion of cooperation. In the future, it is likely for competing firms to cooperate in their production or distribution. Sharing warehouses and trucking capacity has apparent synergies, but what about shared (and possibly flexible) production facilities? Building full capacity before final approval creates a substantial financial risk for vaccine manufacturers. For example, AstraZeneca and Johnson & Johnson are developing their viral-vector potential vaccines and building their respective vaccines' production capacity if approved. However, the production flexibility could reduce their financial risks if they shared their capacity, especially if only one of the two competing vaccines is approved. Through cooperation, both competing firms win, and more vaccines can reach the market faster (Dai and Tang, 2020c), although there are other scenarios too: both vaccines are approved, or neither vaccine is approved.

- Q5. What is the reasonable price that a firm should charge for producing for its competing firm to facilitate this capacity-sharing cooperation? Will this kind of cooperation result in a win-win situation?
- Q6. What kind of licensing contract should both firms establish for the production of vaccines and other critical supplies?
- Q7. Under contingent scenarios, how much capacity and type (fixed or flexible) should two companies with substitutable products create?
- Q8. When should two manufacturers of substitutable products manufacture each other's products to use their capacity better?

Companies and the government. We used different government subsidy and support schemes to illustrate various programs during the COVID-19 pandemic. For example, with government subsidy, companies are motivated to set up partnerships like the one between Ventec and GM for ventilator production (Nickelsburg, 2020; see also risk-sharing contracts with the government by Eckerd and Girth, 2017). However, most support programs are temporary. Therefore, it is of interest to examine the following research questions:

- Q9. When the pandemic is over, what will happen to this partnership when the subsidy is no longer available, and when the demand for the product produced by the partnership is much lower? How should each party deal with excess capacity?
- Q10. How should each party share the value when the size of the pie shrinks?

Lockdown created more disruption than the infection. So, there are also questions on coordination between business and government and how to exit from lockdown (Gilles, 2020).

- Q11. How should business and government coordinate lockdown start and end?

Public-private partnerships to build an 'industry commons.' Even in a free market, government interventions may be needed for critical products such as drugs, vaccines, and PPE in the near term. In general, the government's role in supply chains, even humanitarian ones, deserves much attention (Quarshie and Leuschner, 2020). The government formulating an industrial policy and business incorporating that into operations is critical (Spring, et al., 2017). The US Senate proposed bills to strengthen visibility into medical supply chains to ensure safety and security in May. Some oversight is needed to provide some continuity; some private-public partnerships will spark innovative collaborations like the one between GM and Ventec for the production of new ventilators. After decades of offshoring, the US government and industry bodies should engage with and through university research centers to create an 'industry commons' (Pisano and Shih, 2009). The government should offer subsidies and ease regulations from EPA or other agencies to make

reshoring less costly for US manufacturers (Tang, 2020). Hence, some research questions come to mind:

Q11. Why and how should a private sector entity participate in an industry commons?

Q12. How will government efforts to create an industry commons lead to higher social welfare?

In summary, we listed the various challenges in 2020 with the pandemic-related and other ongoing disruptions extended over time and with many concurrent factors. These challenges help us illustrate 'extreme' conditions requiring measures that go well beyond supply chain management and supply chain risk management. We then followed up by listing various companies' and governments' responses, but, while useful, these measures are not adequate. Such extreme conditions have not ended yet and will likely repeat in future years. So, there is a need to rethink SCM by way of what we have termed 'extreme supply chain management.'

We have listed some research opportunities that have not been addressed in the literature. Based on industry and government responses, research in the areas listed above would be useful for business, society, and the government in being better prepared next time we face similar extreme conditions. A case in point is ventilator production – even though the effort was not useful, it has opened up vistas in cooperation in project-based supply chains and sharing resources like capacity with competitors. Other opportunities we listed pertain to retailers' survival who have to compete with e-commerce giants like Alibaba, Amazon, and JD.com, who have been extremely successful due to Covid. There is also the mixed use of robots and human workers motivated by social distancing and labor's non-availability. The growing role of government in supporting business, including creating industry commons, presents an especially attractive avenue for further research.

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