



Digital technologies and circular economy in supply chain management: in the era of COVID-19 pandemic

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Received: 10 August 2021 / Revised: 1 October 2021 / Accepted: 18 October 2021 / Published online: 11 May 2022
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Abstract

This empirical study aims to identify the importance of Digital Technologies (DT) as an enabler in the Circular Economy (C.E.) based business model, especially during Covid-19. The concept of 'circular economy' has now been advocated as a methodology to stimulate economic growth in line with the environmental sustainability. Hence, the practices of recycling, reduction, reuse/re-manufacture, and repairing (4R's) are deemed to be the core of a circular economy. Recently, the advent of the pandemic Covid-19 has forced the nations of the world to resort to alternate resource use in their manufacturing and trading of goods and services as the supply chains have almost remained disrupted since Covid-19 appeared. We investigate the impacts of Covid-19 upon the use of technological innovation (T.I.), circular economy practices (CEP), and organizational performance (ORP) incorporating the Structural Equation Modeling (SEM). Our results show that Covid-19 significantly impacted the adoption of technological innovation, circular economy, which leads toward organizational performance. Moreover, the practices and operations under the circular economy framework also appear to influence organizational performance significantly. Our study findings bring forward meaningful insights into improving CEF-cum-technology based practices in developing and emerging markets in Asia, and convey significant implications for the business community, policymakers, and researchers.

Keywords Circular economy framework · Organization's performance · Technological innovation · Sustainable supply chain management · Covid-19

1 Introduction

The approach of circular economy (C.E.) based practices is one of the most recent ways of addressing environmental sustainability (Hazen et al. 2020; Murray et al. 2017; Sharma et al. 2021). The concept of C.E. first broached by

Leontief (1928) in 1928 and got its first global application in 1996 by virtue of a law on C.E. passed by German Parliament (Andersen 2007; Bilitewski 2012; Pan and Richardson 2015). United Nation's World Commission on Environment and Development (WCED) released in 1987 the oft-cited report titled "Our Common Future" (aka "the Brundtland Report")

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(Brundtland 1987) and proposed the famous term "sustainable development" defining it as follows: "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland 1987).

According to the commission, the following are the prerequisites for the achievement of sustainable development agenda:

- i. An economic system that is capable of producing technical knowledge and surpluses self-reliantly on a sustained basis;
- ii. A manufacturing sector entrusted with the obligation to preserve the very ecological base of the economic system for eventual development.
- iii. A global system fostering finance and trade on sustainable patterns.

Another more comprehensive definition of sustainability by Hawken (1993) includes the economic terms, as follows: "an economic state where the demands placed upon the environment by people and commerce can be met without reducing the capacity of the environment to provide for future generations." Elkington (1994) introduced the notion of the "triple bottom line", thereby encouraging the evaluation of industrial activities and practices across the social, financial, and environmental dimensions. Later on, he recast the fundamental three dimensions as "People, Planet, and Profit." In another study, McDonough and Braungart (2002) proposed an ecological concept with the metaphor as "waste = food" to model the systems where wastes from the manufacturing and other industrial processes happen to be the inputs to other processes. Recently, the slogan of Circular Economy Framework (CEF) has emerged and is in full swing as a consequence of the integrated efforts by the several schools of thought to synthesize the concept of sustainability into a single construct. The modern paradigm of the circular economy stands as a potential approach to increase the allocative efficiency of resources to achieve an ideal harmony and balance between the society, economy, and the environment.

The concept of 'circular economy' (C.E.) has now been advocated as a methodology to stimulate economic growth in line with environmental sustainability (Korhonen et al. 2018; Khan et al. 2021a). The notion of C.E. refers to the ideas of environmental up-gradation, integration of industrial development, and inspiration of new corporate governance concepts based on corporate social responsibility (CSR) that could result in social benefits at large. Eventually, the C.E. idea is based on the sustainable use of natural resources leading to the

reuse, recycling, recovery, and re-manufacturing practices for waste reduction (Domenech and Fokeer, 2021; Yu and Khan 2021b; Gregson et al. 2015). Hence, the practices of recycling, reduce, reuse/re-manufacture, and repair (4R's) are deemed to be the core of a circular economy (Barreiro-Gen and Lozano 2020; Geissdoerfer et al. 2018; Khan and Yu, 2020; Khan et al. 2021b). However, the advent of pandemic Covid-19 has forced the nations to resort towards alternate resources used in manufacturing and trading of goods and services as the supply chains remain disrupted. Under these circumstances, the role of smart technologies, taking the form of internet-enabled systems, becomes important towards organizational performance both locally and globally. The digital applications and devices are the primary mediums and the modes through which the digital nomads transform or process the digital inputs into digital outputs, and it can be electronically done at any place or point where the internet connectivity and power supply are available (Ünal et al. 2018; Nash et al. 2018).

A pioneer report by Ellen MacArthur Foundation (EMF 2020) refers to three pillars of circularity, i.e., the conservation of natural resources, production optimization, and efficiency of the process. However, various ideas that have arisen and have been built through the pandemic seem to be, at best, based on the former two. Given the relationship between the circular economy and the supply chain (S.C.) management, it is perceived that the circular economy tends to augment the resource proficiency vis-à-vis performance of the environment at every level of S.C. Management (Heyes et al. 2018). The goal of the circular economy would have remained an arduous mission had there been no progression of smart technologies both in terms of computerization and digital technology. The merging of the industrial process with digital technology has resulted in the easy conversion of linear economies into circular ones. Hence, the application of circular economy has been shepherded by the technological concentration (Bergendahl et al. 2018; Khan et al. 2021c; Khan et al. 2021h; Yu and Khan 2021a).

It is conceived as a sum of continuous and positive development cycles that ensure the preservation and enhancement of natural capital, optimization of resource yields, and minimization of the system risks through the management of finite stocks and renewable flows of resources working effectively at every scale. This vibrant economic model eventually seeks to decouple global economic development by virtue of finite resource consumption (EMF 2013). Subsequently, by the development of certain quantitative measures, acceptance of the typical concept of three-dimensional sustainability construct was improved and established by describing the systems involved. For example, the tools like Life Cycle Assessment, the Embodied Energy calculations, and Carbon/Water footprints have helped popularized the construct of sustainability into the conscience of masses over the globe. The researchers have also further emphasized

the need to quantify the degree of circularity through similar tools in the economic systems (Lonca et al. 2018; Su et al. 2013).

1.1 Sustainable supply chain management and circular economy framework

The flexibility relating to the various aspects of manufacturing namely quality, cost, speed, and processing innovations help organization in acquiring a competitive advantage and evolving a sustainable supply chain (SSC) (Bag et al. 2020; Bai et al. 2020; Hazen et al. 2020; Sharma et al. 2021). Ever-changing business dynamics, preferences of customers and suppliers, and the marked shift towards disruptive and smart technologies have significantly necessitated the supply chain flexibility as well as sustainability. Sustainable Supply Chain (SSC) flexibility supports the firms combat the uncertainties and complexities involved in the SC management by offering reliable and sustainable outcomes (Bai et al. 2020). In general terms, SSC flexibility is very much linked with the firm’s capability to efficiently use environmental technology, develop green supplies and products, and eventually minimize the resource consumption (Chirra et al. 2020). In the same vein of thought, circular economy (CE) is regarded as an emerging economic and business model providing the firms with an alternate pattern of resource usage (Jabbour et al. 2019). CEF based practices ensure increased value creation through the resource recovery and renewal once a product has lived its practically useful life (Jabbour et al. 2019). Belhadi et al. (2021) have stressed upon adequate coordination amongst all of the major the stakeholders to overcome the novel challenges of the global Covid-19

pandemic, and emphasized upon the accelerated utilization of the digital and smart technologies.

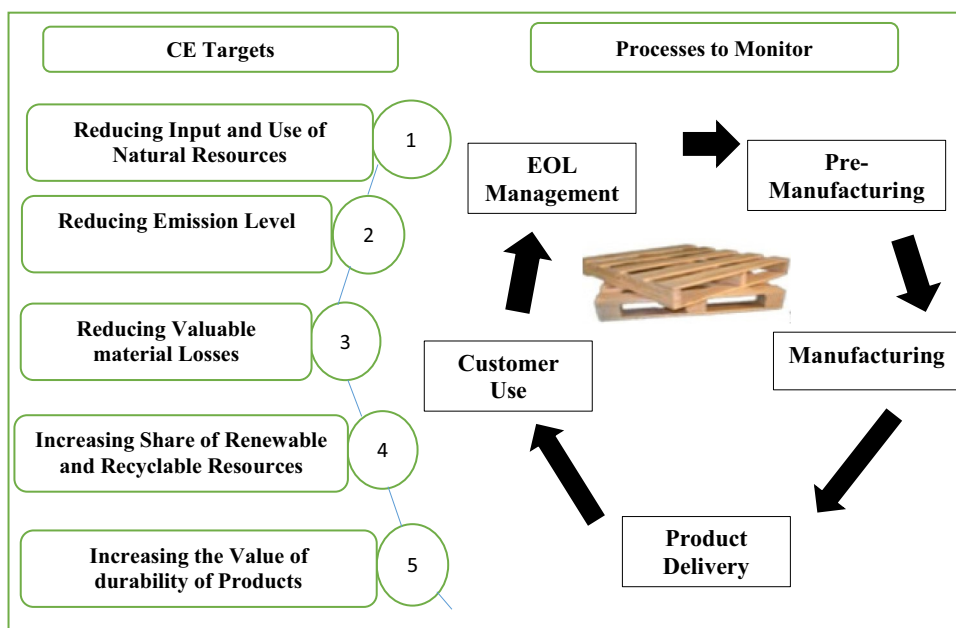
CEF based practices are now considered helpful in achieving the objectives of targeted business performance through pollution prevention, reduction of hazardous emissions, avoiding energy leakages, recycling and closed flow of materials, and ensuring minimum usage of virgin materials (Bai et al. 2020; Jabbour et al. 2019). In the same vein of thought, we refer to, and describe here precisely, the framework developed and illustrated by Gnoni et al. (2018) for explaining the method of assessment as to what extent the product supply chains incorporate the principles of CEF and precisely show how that framework applies the material handling process in the WPSC.

1.2 The Wooden Pallet Supply Chain (WPSC)-circularity illustrated

The WPSC resembles a complex product network managed throughout different life-cycle phases producing certain notable differences in economic and environmental impacts (Bhattacharjya and Kleine-Moellhoff 2013; Bilbao et al. 2011). Gnoni et al. (2018) have explored the various impacts brought about by the decisions made throughout these phases of WPSC, thereby affecting its overall level of "circularity." Fig. 1 presents the certain phases of the WPSC in relation to the CEF, as also detailed in the following discussion explaining the vital decisions at certain stages that affect the circularity of the available decision alternatives.

- **The Pre-manufacturing phase:** At this stage, the decisions regarding the design and nature of the material to be used of the pallets are made as follows:

Fig. 1 The CEF phases and targets in the pallet supply chain (Source: Gnoni et al. 2018)



- i. selection of material, evaluating the alternatives such as virgin wood or recycled wood;
- ii. the selection of pallet type, the available alternatives are stringer pallet, the block form, and non-standard pallets.

• **The Manufacturing phase:** At this stage, a decision is to be made about the manufacturing processes, the sources of energy, and appropriate technologies to be used for manufacturing pallets as follows:

- i. the manufacturing processes and technologies are offering the reduction in scraps and improvement in quality.
- ii. selection of the source of energy (renewable or not).

• **The Product delivery phase:** At this stage, the decisions regarding the type of product to be delivered on pallets and the structure of the product's supply chain are made as follows:

- i. the handling and loading policies;
- ii. the per pallet Quantity of products– deciding about one pallet-one product (e.g., equipment); versus the multiple items per pallet;
- iii. the logistics and transportation practices (the type of loaders, the routing policies, and carriers' capacities);
- iv. the nature and features of the supply chain (e.g., number of echelons in the supply chain, and participants involved (domestic vs. global).

Of the above decisions, the first two impacts the load or weight of the pallet, which further affects its durability and useful life. As regards the third and fourth phase decisions, these affect the mileage traveled and the probability of the success of circularity created by the policies implemented. For example, the providers of pallet pooling attempt to make business deals with the majority of large distributors and retailers who accept goods on the pooled pallets in order to ensure the return of their pallets. By virtue of such arrangements, they are treated as "participant distributors" (P.D.s). Practically, these P.D.s are under obligation to guarantee the return of pooled pallets to the providers, usually through their pallet recyclers' network and in lieu of a commercial fee. By such arrangements, the ultimate return of pallets is effectively guaranteed after closing the loop. Whereas, if the pallet users deliver products to the non-participant distributors (NPDs), such pallets are eventually treated as lost ones, affecting the overall available stock of assets. It is pertinent to mention here that the actual mix of NPDs and P.D.s is not readily known always, and it may change depending upon the

demand of the individual product, and that too at any time (Roy et al. 2016; Khan et al. 2021d).

• **The Phase of Customer usage:** At this stage, the decisions are to be made regarding the ownership of the lot, the tracking system, reverse logistics, and after-sale repair policies of the pallets by the end-users of pallets involved. The policies about reverse logistics include the take-back versus cross-docked approaches. Whereas the repair policies include either the in-house repairs or the outsourced ones.

• **End of life phase:** At this stage, decisions about the end-of-life scenario and available choices such as dismemberment, landfilling, down-cycling, incineration, and mulching are made. The above-mentioned phases of CEF and the operational targets in the pallet supply chain can be pictorially understood as are shown in the Fig. 1.

1.3 Problem statement and significance of the study

Earth is being pushed towards a series of "tipping points," as a consequence of the human activity, with the capability to trigger some very dramatic impacts upon the environmental sustainability aspects that primarily play their role to support the modern society (Heikkurinen 2018). Eventually, the widespread land degradation, climate change, and continuous loss of biodiversity are amongst the known effects of aforesaid human activities that do potentially impact the ecosystems that virtuously guarantee the human survival and sustainment. As has been reported by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES),: "The health of ecosystems on which we and all other species depend is deteriorating more rapidly than ever. We are eroding the very foundations of our economies, livelihoods, food security, health and quality of life worldwide" (IPBES 2018).

In the same vein of thought, Steffen et al. (2015) have argued to align Earth's service capacity with human needs through more eco-friendly-cum-sustainable socio-economic and organizational models that better to pull back from tipping points mentioned above. The concept CEF based practices is being regarded as amongst the most promising approaches to re-organize the contemporary economic and industrial activities for a sustainable future. CEF refers to "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" (Geissdoerfer et al. 2017, p. 776).

Despite the fact that environmental and sustainability challenges have already been identified adequately (Geissdoerfer et al. 2017), potential rewards of implementing the CEF are noteworthy. According to Hazen et al. (2020), CEF has now emerged as a guiding management approach around which other social, political and economic stakeholders at large can rally to

pull the Earth back from the potentially visible environmental catastrophe (Andersen 2007; Ghisellini et al. 2016; Su et al. 2013). As also noted by the Yu and Khan (2021a) that a shift to well-functioning CEF-based regime would raise the Europe's GDP by 0.5% approx. by the end of 2030 along with a net increase of 700,000 in jobs' baseline as compared to the current development regime. However, Tjahjono and Ripanti (2019) posit that despite its prominence, the concept of CEF has attracted a little from the researchers on SSC. According to Hazen et al. (2020), absence of adequate research on CE-related frameworks is striking, and that an efficient SSCM is vital to advance the idea of CEF implementation. Khan et al. (2021) portrays the SSC as the key unit of action and foundation for an effective implementation of CEF based framework and the ultimate success for driving the required change. As such the contemporary researchers of sustainability (e.g., Govindan and Hasanagic 2018; Min et al. 2019; Tjahjono and Ripanti, 2019) term the SSC as the bedrock of global economy requiring the most immediate attention and policy considerations through robust planning framework and CEF based SSC management. Here lies the crux of our problem statement of this empirical study as to how to identify the importance of Digital Technologies as an enabler in the Circular Economy business model, especially during the ongoing Covid-19 scenario.

This study contributes to existing stream of literature in two ways: Firstly, it examines nexuses among smart technologies, circular economy practices, supply chain management, and organizational performance in the contemporary era of Covid-19. Secondly, it attempts to estimate the organizational performance directly through the Covid-19 effect and the indirect means through the lenses of theory of dynamic capabilities. The rest of the debate is organized as follows: the next section reviews the literature on smart technologies, circular economy practices, supply chain management, and organizational performance in the Covid-19 scenario. Section 3 takes on a discussion of the research methodology and tests chosen for establishing the reliability and validity of the research instrument of this study. Section 4 evaluates the study results based on the relationships found among the variables of smart technologies, circular economy practices, supply chains management, and organizational performance in the era of Covid-19. The last section summarizes the conclusions with policy implications/recommendations.

2 Literature review

In the study by Corrêa and Corrêa (2020), an important hypothesis was coined that the pandemic of Covid-19 could foster the application and development of the industrial

practices forming a part of the circular economy. Consequently, a variety of developments were seen that were very closely associated with the production and development of protective equipment (P.E.s), though, in spite of high levels of worldwide demand, these innovative items have been still short of demand even by the health professionals (Corbett 2020; Corrêa and Corrêa 2020; Feng and Cheng 2020; Ha 2020; Lee 2020; Parker-Pope 2020; Subramanian 2020).

In order to meet the requirements of the pandemic situation, the firms, civil organizations, as well as state departments have joined hands and collaborated to manufacture the smart technologies, PPEs from the green materials employing the sustainable practices of the circular economy Corrêa and Corrêa (2020). Firstly, the disposable face masks and variety of shields were manufactured at a mass scale to cater to the basic needs of the medical profession, health centers, and hospitals and then for the whole population (Corbett 2020; Feng and Cheng 2020; Ha 2020; Lee 2020; Parker-Pope 2020; Subramanian 2020). Ellen MacArthur Foundation—the pioneers in promoting the concept of the circular economy, considered the following three pillars of a circular economy:

1. The preservation of natural capital,
2. optimization of resource production, and
3. process efficiency.

Since then, many initiatives have been undertaken, especially due to the pandemic outbreak in recent times, which are mostly founded upon the first two dimensions as most of the production of PPEs was based primarily on the alternative materials that could be reused in the manufacturing process (Hitti 2020; Shokrani et al. 2020). Today's dynamic society is structured in a rather linear production model of basic natural resources' extraction, processing, use, and disposal (Corrêa and Corrêa 2021). Consequently, the disposed of materials need to be returned to the consumer in some useful form and that within a reasonable time scale, as compared to human life span (<100 years), if the current system has to be sustainable (Kümmerer and Clark 2016). For this reintroduction and revamping of the productive cycle, the appropriate processes and rather smart technologies need to be developed and applied within a much improved and integrated manufacturing system empowered by the latest and states of the art techniques such as enterprise resource planning (ERP), balancing, modernization, and replacement (BMR), etc. Most of these technologies can be used to ensure manufacturing through the usage of green and clean methods of energy conversion, renewable resources, and achieving greater efficiency in catalytic syntheses (Belhadi et al. 2021; Catlow et al. 2020; Palkovich and Delidovich 2017; Sheldon 2016; Zhang et al. 2018; Wang et al. 2021).

This above-mentioned approach forms the fundamental basis of the circular economy arena (Kirchherr et al. 2017), wherein the reuse, recycling, recovery, and re-manufacturing practices for the maximum waste reduction are carried on extensively and systematically. One of the fundamental premises of the circular economy concept relates to the valorization and preservation of the natural capital, thereby minimizing the wastages and externalities. Thus, this circular economy concept primarily permeates the revamping of overall production supply chains through technological innovations, starting right from the first idea of product planning and moving to its eventual manufacturing, distribution, and ultimate use and final disposal (Corrêa and Corrêa 2021).

According to Conselho Empresarial Brasileiro para o Desenvolvimento Sustentável (2018), the design of technology involved is a vital tool to achieve the objectives of the circular economy because, by virtue of it, the durable goods and services can be brought in the market with the use of much fewer resources and the state-of-the-art production mode. To keep it short, using the much cleaner processes, along with efficient energy resources, and the modern applications for generating safe by-products guarantee the robustness of the activity from the viewpoint of circular economy (Babitt et al. 2018; Kümmerer and Clark 2016).

2.1 Covid-19 and sustainability

Initially, the Covid-19 outbreak started in China as the first case of Covid-19 was reported to World Health Organization (WHO) by Chinese authorities on 31st December 2019—a patient was found suffering from pneumonia in Wuhan City Hubei Province. (Xu and Cao 2021). China controlled this outbreak within three months and stood its economy again, and the Chinese cities proved to be more resilient against Covid-19 by adopting smart technological innovations (Kummitha 2020). The ever-interconnected world faces the problems of the supply chain, demand, and cause to disaster the global economy due to the lockdown situation across the countries. Societies are transforming in the field of how commodities to be produced and distributed across the country and globe due to the Covid-19 pandemic (Sarkisa et al. 2020). The reduction in economic and manufacturing activities tend to slow down and even negative the economic growth due to the outbreak of Covid-19 and drive the economies to think about using robotics, automation technology in production processes, and use of data analytics and cloud computing to select and manage the suppliers to manage the core supply chain activities (Ibn-Mohammed et al. 2020). The Covid-19 outbreak in China affects the global economy by directly influencing the production, supply chains and indirectly influencing the financial markets (Bachman 2020). Digitalization would be helpful to develop sustainable products and circular economy (C.E.), and a hybrid system of

product-service would boost the transformation of the linear economy (L.E.) to C.E. (Agrawal et al. 2021; Chowdhury et al. 2020).

China was the first country globally that enacted the laws to implement the C.E. framework in January 2009, namely as "China's Circular Economic Promotion Law" (Fan and Fang 2020). The main objectives associated with the enforcement of this law including the optimal rate of utilization and efficient usage of economic resources in production, consumption, and circulation. This law provides the base to promote C.E. for China. The world has consumed the economic and natural resources during the current century that is above the accumulated consumption over the past centuries (Tilton 2003). This ever-rapid increase in the consumption of economic resources threatens the survival of humans living on this planet. There is an urgent severe need to rethink the utilization of resources with greater efficiency with minimum adverse effects on the environment. So, the "United Nations Environment Program 2014" stresses the need to meet the growing needs with optimal resource efficiency without environmental degradation. C.E. not only particularly addresses the resource scarcity and environmental degradation issues but also considers it one of the main drivers to the organizational performance. Like Japan, Germany, United States, and France countries China has developed its own C.E. model to achieve its economic goals. A mounting quantum of research supports the necessity to contemplate applying the C.E. ideals within the supply chains. Regrettably, most of the countries vis-à-vis business entities have not been effective so far in practicing the notion of CEF, mainly due to challenges being confronted by them.

The world has faced different diseases' pandemics in history. These pandemics have improved our understanding and abilities of how to respond to viral diseases, but the wave of globalization also increases the likelihood of the pandemics spread globally. As China controlled the pandemic, there were 118,951 confirmed cases, and 5,537 infected people died as of July 06, 2021, in China (covid19.who.int 2021), and it left significant impacts upon not only of society but also on their working lives. Since that, it has been facing different challenges to cope with this pandemic through various strategies, including more inclination to circular economy and innovations in the information technologies to minimize the Covid-19 effects.

2.2 Covid-19, smart technologies and organizational performance

Smart technology is based on artificial intelligence that can self-monitor, analyze and generate the report for the specific objectives. Organizations are adopting 4.0 technology to optimize their manufacturing processes with minimum errors. There is significant evidence that 4.0 technology and

C.E. reduce the wastages and improve the reuse and re-manufacturing activities (Jabbour et al. 2019). While the world combats with Covid-19 with greater advancements in medicines, medical instruments, biotechnology, artificial intelligence, machine learning, and big data sciences successfully, the satellites, CCTV cameras, drones, automatic vehicles, smart clothes and watches, and mobile apps are being successfully used to control the adverse effects of wide-spread Covid-19 (Waheed and Shafi 2020) and as such the advancement in smart technologies has significantly helped to combat against the Covid-19. Zuboff (2019) has explained how the vendors monetize the digital exhaust and utilize it for constructing the digital footprints that eventually predict and shape the firm behavior and industrial practices especially in the context of ongoing Covid-19 and CEF. Most of the organizations that have survived during the Covid-19 scenario, have implemented the digital tools and technologies to help with the remote work. Most of these cloud-based technologies and applications are primarily hosted by the internet service providers (ISPs) and GPRS based vendors who are contracted for the certain rights, and getting access to some or all of the digital services, and output produced (Leonardi 2020). So, based on the above discussion, we develop the following hypothesis:

H₁: *Covid-19 has a positive effect on the adoption of technological innovation.*

As the Covid-19 pandemic threatened humanity, world economies tried to prevent their inhabitants by implementing lockdown policies by sealing their borders, and it proved a great shock to international trade and badly disturbed the supply chains. The demands of the goods, particularly in food, medicines, lifesaving, and health safety equipment, rapidly increased whereas the manufacturing and distribution for such items had been halted, and that caused to merge the production and distribution networks. Eventually, a tradeoff between the L.E. and C.E. was sought to save the resources based on the hygienic issues for the health safety measures. The C.E. suggests solving these global issues by implementing the techniques like re-manufacturing, recycling, and reuse of economic resources (Nandi et al. 2021). So, based on the above discussion, we develop the following hypothesis:

H₂: *Covid-19 has a positive effect on the adoption of circular economy practices.*

The Covid-19 pandemic has been shifting the work on-site to working online through the supporting technological environment (Foss 2021). To work at other places than sites cause the problems of monitoring and controlling the work performance and, eventually, the managers lose the

loop of coordination. The stress of the Covid-19 pandemic, lockdown of the economy, and lack of coordination among the different economic activities may lead to lower organizational performance. Based on the above critical review, we formulate the third hypothesis as follows:

H₃: *Covid-19 has a negative impact on organizational performance.*

2.3 Technological innovation and organizational performance

Smart technologies guide corporate strategies to improve performance (Tajbakhsh and Hassini 2015). The Covid-19 and lockdown of the economies shifted the traditional manufacturing, trading, and commercial activities to those based on automation and e-business tools. The innovative use of technology in manufacturing and trading activities during the Covid-19 pandemic is highly likely to improve organizational performance. The technological innovations can very much influence the environmental quality in many aspects and accelerate the aggregate production and economic development through driving towards usage of low-carbon energy sources (Haldar and Sethi 2020; Chaudhry et al. 2021; Mongo et al. 2021; Khan et al. 2021g; Urbinati et al. 2018; Yadav et al. 2020). So, based on the above discussion, we develop our fourth hypothesis as follows:

H₄: *Technological innovation improves the organizational performance.*

2.4 Circular economy and organizational performance

C.E. means three "R principles," including reuse, recycling, and reducing the economic resources to the minimum, the negative effects on the environment, and maximum economic benefits (Gharfalkar et al. 2018). The C.E. practices are being successfully implemented in the agri-food and industrial sectors, water, and waste management concerns to improve the business performance (Khan et al. 2021e; Gravagnuolo et al. 2019). Sarfraz et al. (2021) find that sampled firms from C.E.s of Chinese, Romanian and Italian economies have a positive relationship with organizational performance. According to the first large-N-study on the practices of circular economy and related barriers in the European Union (E.U.), Jacob et al. (2021) report that certain cultural barriers, including constrained consumer awareness and interest as well as hesitant company culture, are the main hurdles by businesses and policymakers. These market-related barriers are mainly induced by a sheer lack of synergistic governmental interventions to accelerate the paradigm shift toward the adoption of CEF. China is the first

country in the world to implement C.E. framework to use the resources effectively and efficiently. Specific C.E. features of the Chinese model, including reuse, re-manufacturing, and recycle, lead it to compete with the rest of the world with cost leadership strategy. The Chinese firms under the C.E. framework may be able to perform better by having green procurement and transportation to manage their supply chains and distribution networks. There would be flexible policies to respond to the viral outbreak nationally and as well at globally (Saunders-Hastings and Krewski 2016). C.E. is preferable to improve organizational performance (Khan et al. 2021f; Sarfraz et al. 2021). Based on the critical review, we formulate the fifth hypothesis as:

H₅: Circular economy practices increase the organizational performance.

3 Methodology

Due to the nonavailability of a typical consensual and standard questionnaire to measure the industrial and economic activities relating to the circular economy and technological innovation, the current research work employed the fundamental principles required to establish a circular economy framework (CEF) as tabulated by Ellen MacArthur Foundation (EMF 2020) coupled with the dimensions of WPSC explained earlier as the empirical references to prepare the questionnaire of this empirical study. These practices primarily relate to CEF, such as conservation and growth of natural resources, human capital, optimizing the resource allocation, and efficiency of industrial processes.

The study was conducted by sampling the Chinese manufacturing firms. A number of 480 firms' representatives were contacted through WeChat, WhatsApp, Q.Q. Messenger and E-mails to fill up the questionnaires. In

response, we received 277 filled questionnaires (response rate of 57.7%) and were used for the analysis and testing of hypotheses employing SEM technique and using SmartPLS 3.0 tool. The sample size and responses were considered adequate to understand the phenomena and run selected statistical testing empirically as was also adopted recently by Edwin et al. (2021). Our study empirically investigates the impacts of Covid-19 upon the use of technological innovation (T.I.) and circular economy practices (CEP) on organizational performance (ORP). The Fig. 2 depicts the model of our study wherein the research framework connecting the underlying constructs was developed on the basis of underpinning theory of dynamic capabilities.

3.1 Data reliability and validity

The model used in the study conforms to the benchmarks of internal consistency, convergent, and discriminant validity tests. In order to check the reliability and validity of the measurement items of variables used in the study, the prerequisite analyses were performed to authenticate the validity and reliability of the questionnaire items. First, the factor analysis was performed, and the validity of construct items was established by the factor loadings appearing against the indicator items in Table 1 below. Only three of the items have factor loadings between 0.748 and 0.800, while all of the remaining indicators have factor loadings between 0.800 and 0.909, representing the high reliability of the constructs formed by these items. In Table 1, in the column next to the factor loadings, the values of the Cronbach alpha have been reported for each of the constructs, and all of these values establish the reliability of the measurement items. The further requirements of analysis have been performed, and the results have been presented under the following headings:

Fig. 2 Authors' Conceptualized Study Research Model

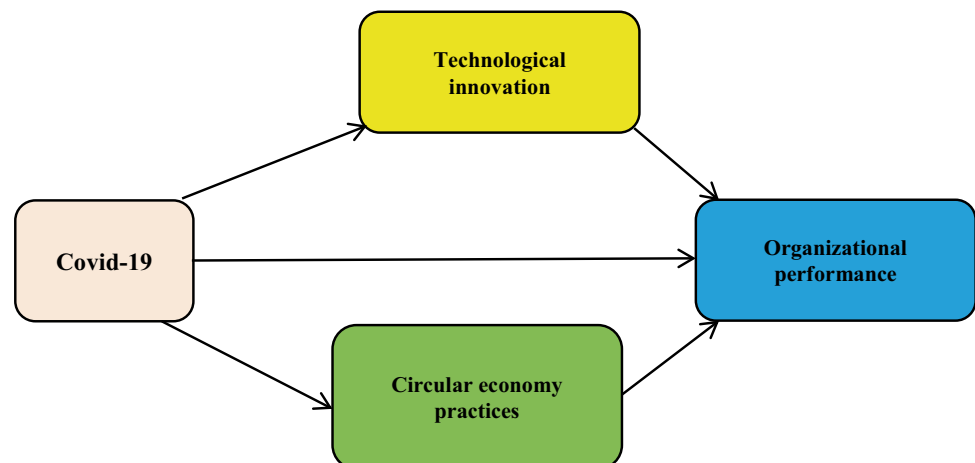
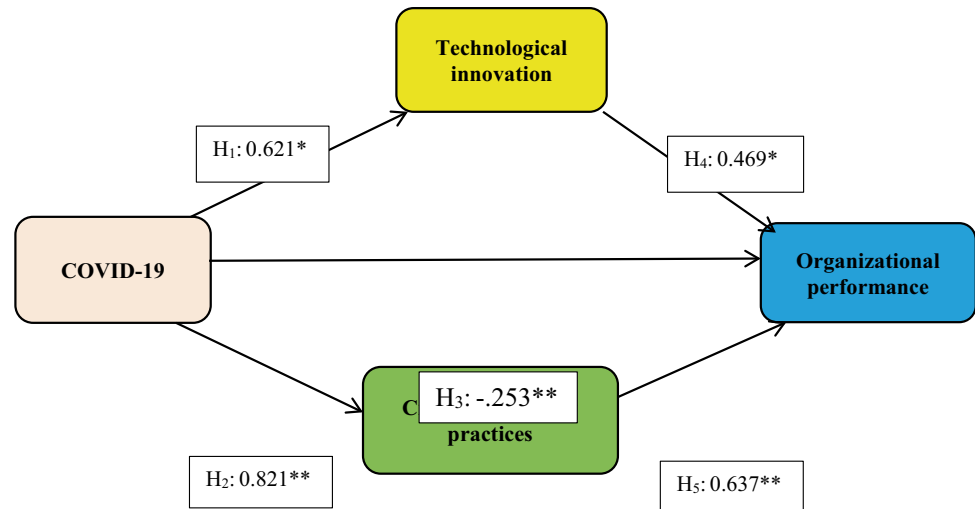


Fig. 3 Graphical representation of the results of the main structural equation model. Note: ** and * show the significance level at 1% and 5%, respectively



3.1.1 Composite reliability

For the purpose of construct validity check, a score of reliability above 0.6 is a sufficient requirement of the reliability,

which is sometimes also called reproducibility and consistency. It means that the measurement items are capable of yielding the same results consistently, therefore, are error-free. The score of reliability can also be used to judge the

Table 1 Factor loadings and reliability indicators

Variables	Indicator	Factor Loading	Cronbach's α	CR	AVE
Covid-19					
Personal perceived risk (PPR)	PPR1	0.791	0.812	0.835	0.753
	PPR2	0.865			
	PPR3	0.844			
Govt Policies (P)	P1	0.859	0.887	0.909	0.815
	P2	0.898			
	P3	0.903			
	P4	0.909			
Circular Economy Practices (CEP)					
Green procurement (GP)	GP1	0.886	0.917	0.923	0.764
	GP2	0.919			
Green transportation (GT)	GT1	0.808	0.899	0.909	0.679
	GT2	0.831			
Technological Innovation (T.I.)					
Information sharing ability (ISA)	ISA1	0.838	0.822	0.799	0.671
	ISA2	0.876			
	ISA3	0.835			
	ISA4	0.874			
	ISA5	0.846			
	ISA6	0.789			
Coordination and integration ability (CIA)	CIA1	0.839	0.841	0.865	0.783
	CIA2	0.862			
	CIA3	0.813			
	CIA4	0.831			
Organizational Performance (ORP)					
Economic (ECO)	ECO1	0.873	0.844	0.867	0.771
	ECO2	0.855			
Operational (OPP)	OPP1	0.831	0.857	0.797	0.724
	OPP2	0.748			

degree of consistency among the different measurements of the variables in the Model (Hair et al. 2006, 2014). Operationally speaking, the reliability represents the internal consistency of the research instrument used to assess the degree of homogeneity of the measurement items representing a particular construct of the model. For the reflective measurement items as in this thesis, all of the items are considered as the parallel measures capturing the common construct in the model. The values ranging between 0.60–0.70 are also acceptable in case another measure of the validity of the construct is good enough (Hair et al. 2006, 2014). The values of AVE and the composite of all the constructs of the model are represented in the Table 1 and are showing an adequate level of internal consistency.

3.1.2 Discriminant validity

The measure of discriminant validity is used to analyze how well a particular construct is theoretically distinct from the other ones in the model being tested. Technically speaking, the loading of an item on its relevant variable is required to be higher than its cross-loadings on other variables. It is then checked by comparing the values of AVEs with the squared correlation of each of the latent constructs.

As per recommended criteria, the squared root of the AVE value should be higher than the squared correlation between the latent constructs (Cooper and Zmud 1990; Hair et al. 2017). In our data output, the discriminant validity is proved as the following two requirements are being fulfilled:

1. The correlation of variable score with the measurement items evidences an acceptable pattern of loading on the factor assigned, as compared to any other factor.
2. The squared root of every value of the construct's AVE is higher than 0.5 (Fornell and Larcker 1981) and any other correlation among any of the pairs of the latent constructs. In Table 1, the check values of discriminant validity are well above the minimum criterion of 0.50.

In the analysis of multiple regression analysis of structural equational modeling (SEM), discriminant validity refers to

the extent to which a construct is truly distinct from the other constructs in the model (Fig. 3). The discriminant validity test is done by comparing AVE values of the constructs with the squared correlation for each of the constructs. The rule of thumb for assessing discriminant validity requires that the square root of AVE be higher than the squared correlations between constructs (Cooper and Zmud 1990; Hair et al. 2017).

3.1.3 Convergent validity

This type of validity is established when the questionnaire items correlate with that construct strongly to which they relate, and thus the construct is considered well theorized. Technically speaking, the measurement items must share a high proportion of variance in common and thus converge on the relevant construct with the range of values between zero and one (1–0). Regarding the reflective indicators, a minimum of 0.70 is the required level of ideal standardized loading, but down to 0.60 of factor loading can be accepted as well (Barclay 1995), especially in management sciences. The t-statistic about each of the factor loading was analyzed to verify the convergent validity of the measurement items of this study's research instrument, and factor loadings were found to be greater than 0.70 (See Table 2).

3.1.4 Testing the model fit indices

The significance of the coefficients of paths in the analysis was determined using a bootstrapping method with the 1000 samples. The significance was then determined by using a one-tail Student's T distribution test at a 0.5 significance level. The R^2 measures the construct variance explained by the model. Good fit exists in our model tested as the value of R^2 measure is high and indicates that our empirical model testing provides a good fit for the latent constructs for use in Partial Least Square Regression in our non-time series study (Chin 1998; Gyau and Spiller 2007). The Table 3 presents the results of SEM analysis for the confirmation or rejection of the hypotheses. Whereas Table 4 presents the T-Statistics and therefore helps to analyze whether our hypotheses formulated for testing are significant or otherwise.

Table 2 Reliability and convergent validity

Variables	PPR	P	G.P	GT	ISA	CIA	ECO	OPP
PPR	0.799							
P	0.597	0.812						
GP	0.493	0.657	0.835					
GT	0.542	0.619	0.792	0.659				
ISA	0.531	0.677	0.788	0.652	0.819			
CIA	0.629	0.551	0.625	0.541	0.765	0.828		
ECO	0.478	0.589	0.567	0.599	0.738	0.777	0.758	
OPP	0.368	0.664	0.416	0.492	0.578	0.698	0.525	0.875

Table 3 Goodness-of-fit Indices

Fit Indices	Chi-square/df	Root mean square error of approximation	Goodness-of-fit-index	Adjusted goodness-of-fit-index	Normed-fit index	Tucker-Lewis index	comparative fit index
Recommended criteria	<3	<0.08	>0.9	>0.80	>0.90	>0.90	>0.90
Model results	2.411	0.054	0.912	0.818	0.925	0.937	0.935

4 Analysis and discussion

From the analysis of the regression output Table 4, we conclude that the Covid-19 has a significant impact upon the adoption of technological innovation, circular economy, and the overall organizational performance. These findings conform to those of Corrêa and Corrêa (2020), Ingemarsdotter et al. (2020); Ranta et al. (2021) and Vegter et al. (2020). This reinforces the idea that the Covid-19 like situations could trigger the use of circular economy practices faster than those of the normal settings. Moreover, the practices and operations under the circular economy framework also appear to influence organizational performance significantly. This finding is quite compelling and is validated by the extant research studies, e.g., Su et al. (2013), Ghisellini et al. (2016), and Urbinati et al. (2017).

The findings further reveal that technological innovation has a significant and positive impact on ORP. The basic premise is also corroborated in the empirical findings that technological innovations have emerged with an enormous impact on the organizational performance (Yam et al. 2004) as the ORP may be perceived to be the outcome of an interactional process typified by technology-related uses across the hierarchy of the firms (Teece 1996). Innovation augments technological competence (Daniels 2002) and tend to stimulate the organizational performance (Galende and Fuente 2003). In a similar line, Ranta et al. (2021) provided significant contributions regarding the understanding of how the digital technologies facilitate the individual firms in their real-life settings to improve resource flows, as well as value creation and thereby innovate their business model according to CEF. As such, our study also highlights the critical role of advanced knowledge management in the

contemporary dynamic business operations of firms engaged with the CEF transition in China. Our finding on the significant impact of technological innovation upon the ORP corroborates the findings reported by Ranta et al. (2021), who have provided significant contributions on an understanding of how the digital technologies facilitate individual firms in their real-life settings to improve resource flows, as well as value creation and thereby innovate their business model according to the CEF. Perse, our findings also tend to highlight the critical role of advanced knowledge management in contemporary dynamic business operations of firms engaged with the CEF transition in China. In the manufacturing firms, adoption of CEF-based practices and allied capabilities can definitely help making decisions taking care of the sustainability considerations thereby translating related circular strategies for the achievement of the ‘United Nation’s (UN) 12th Sustainable Development Goal’ (Kristoffersen et al. 2020; Machado et al. 2020). Our results identify a positive association between the two of significant variables in the research model of this empirical study.

Our study results corroborate the findings reported in the previous studies about the nexus of CEF-based practices and firm performance (Bai et al. 2020). Moreover, the CEF-based initiatives appear to play significant role in improving the SSC management-based performance in the sampled manufacturing industries (Belhadi et al. 2021).

In the same vein of thought, Tunn et al. (2020) have focused upon the access-based product-service systems (AB-PSSs), such as the sharing systems of bicycles, as an example of typology of the circular business model (CBM) affecting the consumers' experiences and attitudes. Their findings seem to have established how digitalization spread can be instrumental in the expended mobility AB-PSS and

Table 4 The results of hypotheses' testing

Hypotheses	Paths	Expected Sign	Standardized estimate	P-value	Results
1	COVID-19 → TI	+	0.621*	0.043	Supported
2	COVID-19 → CEP	+	0.821**	0.001	Supported
3	COVID-19 → ORP	-	-0.253**	0.000	Supported
4	TI → ORP	+	0.469*	0.021	Supported
5	CEP → ORP	+	0.637**	0.000	Supported

** and * shows the significance level at 1% and 5%, respectively

the ever-increasing dependence of users' experiences of digital aspects, including the 5-G technology. Our results also confirm the findings reported by Ingemarsdotter et al. (2020) that suggest how the CBM-based service model can help in improved monitoring, tracking, and predictive maintenance, thereby ensuring effective evaluation of the remaining life period of used products and durability. The circular economy helps to implement heterogeneous innovative methods which are dissociated from utilization of predictable asset reserves. The ideals of CE lead towards minimizing of the value destruction in organization systems and assist towards maximization of the value creation process of organizational activities. The adoption of circular approach may facilitate an organization towards attaining more sustainable (economic) outcomes (Barros et al. 2021). By the same notion, the circular economy is seen as impacting the organizational performance positively, and these findings are consistent with those of the extant research conducted by Anthoula (2016) vis-a-vis Mol and Birkinshaw (2009).

5 Conclusion and policy recommendations

While Covid-19 looks like a destructive element to business growth and world economies, it also presents opportunities for innovation and marketing. The countries must now invest in technology and provide incentives for developers of online platforms and mobile apps so that many businesses can afford this technology to survive in the various markets they are operating in. This empirical study allows identifying the critical aspects relating to technology and supply chain management that have affected the implementation of CEF-related practices during the Covid-19 period in the sampled industries of China. The findings of this study are supposed to help to understand the successful business strategies, peculiar procedures, and measures adopted by the leaders and managers of Chinese industries while switching towards the CEF. It can be safely argued that the Covid-19 scenario puts high demands upon the policymakers to play their critical role to make the transition towards the CEF a success through appropriate policy measures and the recommended frameworks, especially in the context of the leading and rather larger organizations. This empirical study is expected to inspire more future work by the researchers and scientists in the field of business model up-gradation through modern digital technologies and gradual transition towards CEF-based sustainable growth. The present study adds to the extant literature on the sustainability aspects of SSC management by associating four of the significant research areas: firm Performance, SSC management, smart technology innovation and the CEF-based practices. Majority of the research studies examined the nexuses between above-mentioned concepts in a rather scattered manner, focusing

less attention on understanding how these constructs interact with each other (Chirra et al. 2020) whereas present study have elaborated that the STI capabilities serve as an effective enabler for both SSC management and CEF based practices.

5.1 The practical implications

One of the vital implications of the Covid-19 affected SC management is the experts' logical prediction that during and in aftermath of the global Covid-19, we will now be entering an era where the remote operations and online working will become the 'new normal' phenomena Leonardi (2020). If this prediction comes fairly true, then the organizations and their performance will definitely be shaped, remodelled, and quantified and in different unknown ways and unique models. Regardless of the fact whether the remote or online working remains common, or whether it becomes merely a brief spike or spark in the modern history of starts and stops (smart lockdown practices), it is quite likely that all of the digital footprints produced during Covid-19 can and will serve as the basis for many modern and innovative organizational ideologies, policies, and practices, especially the digital and CEF based sustainable industrial operations in the future. Another significant outcome of the use of DTs is the increased recording and storage of digital exhaust. The online activities undertaken through the digital technologies generate time stamped logs of employees' behavior. These logs of employee behavior or meta-data are termed digital exhaust. A major thrust in the use of DTs during the contemporary Covid-19 scenario has affected corresponding increases in the quantity of work logs being recorded in the real time online-processing. As rightly posited by Leonardi (2020), three of the most significant second-order effects and implications of working remotely through digitalized tools and online that could shape the trajectory of working for several decades to come are as follows:

1. working online creates huge amounts of the digital exhaust;
2. The available digital exhaust can be used for turning concerned staff into data representations; and
3. eventually, such data representations can be utilized by Artificial intelligence (AI) for predicting (and shaping) the employees behavior.

The organizations ought to understand and precisely internalize circularity principles within their strategic planning process, hence connecting their strategic goals with maximizing efficiency, reducing wastages, and most importantly, discovering novel sources of revenue that can enable both business success and the regeneration of environment (Barros et al. 2021). Additionally, it also demands coherent

shift in the governmental policies (Buren et al. 2016) and, thus, all the culture rooted therein. On a positive note, this empirical study is expected to inspire future research in the field of business model up-gradation through modern digital technologies and gradual transition towards CEF-based sustainable growth.

5.2 Study limitations and future research agenda

The authors acknowledge that several research questions exist in the much complex research domain that lies at the intersection of the CEF-based circular business models and digital technologies, which invariably call for much deeper and broader investigations. However, this study has still provided an attempt to fill some of the relevant existing gaps and has empirically contributed towards nurturing and understanding the relevant ideas and thus motivate further contributions into the contemporary work of researchers on innovative digital technologies and sustainable circular business models. Future researchers may well explore rather broader areas of business model applications, business process re-engineering, sustainability science, and technological innovation and SSC management.

It is also recommended to study and understand the perspective of rather a majority of firms comprising the SME sector to remove the barriers hindering the ongoing paradigm shift towards CEF, and as such, the findings may also help the policymakers to adopt a proactive approach regarding the much-neglected sectors especially in the emerging as well as the developing nations like China, Pakistan, Bangladesh, India, etc. as was also highlighted in the recent studies (e.g., Prieto-Sandoval et al. 2021; Trigkas et al. 2020). The same recommendations can be traced to the findings reported by Sawe et al. (2021) to explore the people-driven factors (PDFs) responsible for the implementation of CEF in the SME sector, especially in developing economies.

A number of limitations in the development and design of current study need to be recognized. Firstly, the constructs and theoretical framework of current study are based on theory and may or may not address the issues associated with the practical aspects of CEF. As such, the future studies may well adopt a mixture of quantitative and qualitative methodologies to re-examine the associations hypothesized in our proposed model. Secondly, our study results are subjected to the limitations of cross-sectional design and procedures of data collection. Thirdly, the future studies may employ in-depth longitudinal research design to confirm the nexuses among SSC management, CEF based practices, and firm performance. Finally, the future researchers could triangulate our study findings by examining how the CEF based practices and SSC management are linked with firm performance in the other sectors like healthcare, transportation and tourism during and after the Covid-19 scenario.

Funding This research was funded by Fujian Center of Theoretical System of Socialism with Chinese Characteristics (grant number: FJ2020ZTZ011).

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