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Adoption of technological innovation and recycling practices in automobile sector: under the Covid-19 pandemic

Zhang Yu[1] · Muhammad Umar[2] · S. Abdul Rehman[3]

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Abstract
Rising environmental concerns and globalization of supply chain made their control and management difficult. Blockchain technology, as a distributed digital ledger technology, guarantees security, visibility, traceability, and transparency promises ease for environmental and global supply chain problems. In this research work, blockchain technology and business analytics techniques were critically analyzed in the context of supply chain. Global and local governmental bodies, consumers, and communities are putting pressure to meet sustainability goals, which prompts us to investigate how these technologies can address and aid remanufacturing and recycling practices and sustainability in supply chain. The results illustrate that advanced technologies have a key role in the implementation of remanufacturing and recycling practices. The results also indicate that the remanufacturing and recycling practices substantially improve automobile firm performance. Moreover, the results also indicated that Covid-19 pandemic has positive moderating effect between advanced technology and remanufacturing and recycling practices while having insignificant effect between remanufacturing and recycling practices and automobile firm performance.

Keywords Technological innovation · Recycling practices · Automobile sector · COVID-19 pandemic

1 Introduction

In the current era of economic development, Covid-19 (COD-19) has caused disruption on large scale across the globe (Linton and Vakil 2020). Almost all aspects of life including global supply chain (SC), human activities, and trade affected adversely (Khan et al. 2021a, b, c). Researchers have illustrated that out of 1000 top companies in the world, 94% were affected because of this pandemic (El Baz and Ruel 2021). For instance, the UK automobile suffered a loss of £8.2 billion by the end of 2020 (Sharpe 2020) in Europe and across the globe huge losses suffered by manufacturing firms due to halt in production operations. Because of disruption in global SC, the firms also faced scarcity of resources and risk in their production operations as the trade activities were halted to stop the spread of the virus (Anser et al. 2020). In restricted pandemic circumstances, firms moved towards recycling and remanufacturing practices (RRP) (Khan et al. 2021a, b, c), repurposed their production operations to cope with vulnerability and risks, and to meet the demand of shortage products. In this regard, a firm in Germany halted its production and acquired a face mask manufacturer company to meet the demand of facemasks. Similarly, an automobile firm in China and non-governmental organizations and prison inmates in Malaysia started to manufacture personal protective equipment (PPE) to meet the requirements of basic needs and facilitate governmental calls (Shah et al. 2020). Although the repurposing of manufacturing firm's strategies have provided some positive results but their promising results are limited. In order to have promising results and to have successful implementation of RRP, and repurposing of manufacturing firms operations and strategies, firms need to move towards advanced

✉ Zhang Yu
yuzhang19910522@sina.com

Muhammad Umar
Sheikhumar424@yahoo.com

S. Abdul Rehman
AR1987@gmail.com

[1] School of Economics and Management, Chang'an University, Xi'an, China

[2] Faculty of Business Economics and Social Development, Universiti Malaysia Terengganu, Terengganu, Malaysia

[3] Department of Business Administration, ILMA University, Karachi, Pakistan

technologies (ADT) (Bag et al. 2021; Umar et al., b, c; Wang and Wang 2019). The adoption of which facilitates RRP (Man and Strandhagen 2017) which are part of circular economy (CE) practices (Kerin and Pham 2019; Yu et al. 2021a).

The concept of CE is focused on closed-looped operations (Elhabashy et al. 2019), resuscitating natural resources, and making use of discarded materials and wastage (MacArthur 2013). Increase in deterioration of natural resources, increase in population, vulnerability, and risks because of COD-19, have also led to the need to move towards CE practices (Sharma et al. 2020; Rajput and Singh 2019). Countries across globe such as Malaysia China, European Union, USA, and Japan have started to adopt CE practices (Yadav et al. 2020; Yu et al. 2021a) in various industries including automotive and service (Saidani et al. 2018; Julião et al. 2018) but are in its nascent stage in developing countries (Yang et al. 2018). Researchers have stated that few factors including operations strategy, technological use, planning and controlling, and consciousness among people must be considered for effective implementation of CE (Nascimento et al. 2019; Lin 2018). Research on CE is getting attention and not widely explored in the context of ADT, which includes big data analytics (BDA), blockchain technology (BCT), internet of things (IoT), artificial intelligence (AI), and smart sensors (Umar et al. 2021a, Khan et al. 2021a; Awan et al. 2021) the adoption of which make manufacturing processes intelligent, interlinked and transparent (Kumar et al. 2020; Yu et al. 2021a) helped in making decision regarding production operations (Boccella et al. 2020) and facilitate RRP. Table 1 illustrates the definition of the constructs.

The automotive industry in Malaysia consists of 27 vehicle producers and over 640 component manufacturers. The Malaysian automotive industry is the third largest in Southeast Asia, and the 23rd largest in the world, with an annual production output of over 500,000 vehicles. While, in China, according to the official statistics, there were 115 automobile manufacturers in 2009. The number of automobile manufacturers changed dynamically from 135 in 2001 to 155 in 2007 and then started to decrease. Note that the number includes only the manufacturers that produce both the body and chassis of vehicles. Besides these manufacturers, there are also many manufacturers that buy the chassis from automobile manufacturers and build the body upon the chassis to make special-purpose vehicles, such as fire engines and milk vans. According to Wong (2020), the Chinese automobile industry generates 30% of the world's vehicle production and worldwide automobile industry grew 1.9% yearly because of Chinese automobile industry.

Wyman's report in 2018 had illustrated that the ADT have the potential to digitize the production process of automobile industry through its capabilities, enhanced interaction among human and machine, and will reshape the automobile sector by 2030. Although the adoption of ADT provide enterprises with environmental sustainability but little is known about how ADT facilitate RRP during the pandemic and how RRP can enhance automobile firm performance (AFP) in Malaysia and China. Keeping in view the above discussion following objectives were formulated:

- To ascertain the role ADT (blockchain and business analytics) in RRP.
- To examine the effect of RRP on AFP.
- To investigate how COD-19 moderate the effect among ADT, RRP, and AFP.

The current study is arranged as follows: Section 2 illustrates the review of literature followed by methodology used in the current study. Section 4 elaborates the results and discussion while the last section describes conclusion and guidelines for the policymakers.

Table 1 Definition of construct

Construct	Definition
Advance technology (ADT)	It indicates industry 4.0 technologies such as BCT and business analytics, the adoption of which provide enterprises with smart contracts facility, analyzing ability and enable transparency, integration, and visibility in SC operations (Umar et al. 2021a; Yu et al. 2021a, b)
Remanufacturing and recycling practices (RRP)	RRP are the part of CE practices (Kerin and Pham 2019). The adoption of which provides firms with the opportunity to improve the efficiency of resources, support sustainable production, and lessen waste (Liu and Bai 2014; Matsumoto et al. 2021)
COVID-19 pandemic (COD-19)	COD-19 was a stress test of our globalized economy and of our global goals for a more sustainable planet (Naidoo and Fisher 2020) it is the result of human suffering, economic hardship, and social disruption (Khan et al. 2021a, b, c)
Automobile firm performance (AFP)	It indicates the ability of firms to mitigate and minimize the adverse waste, pollutants, emissions from SC processes and reduce cost linked with energy, raw material, and waste discharges (Green et al. 2012; Umar et al. 2021a)

2 Literature review

2.1 Advanced technology and remanufacturing and recycling practices

ADT and CE are recognized as emerging trends that have the potential to improve the productivity and sustainable performance of firms (Luthra and Mangla 2018; Dalenogare et al. 2018). Under the ambient of ADT, business analytics and BCT are linked to CE, taking in view the broader nature of data and information management (Sarkis and Zhu 2018). The application of BCT is linked with the internet of things (Kshetri 2017), radio frequency identification, and global positioned sensors (Ali and Haseeb 2019), which help trace production operations in CE through gathering accurate data. BCT has various features such as traceability, decentralization, transparency, verifiability, and anonymity (Lu 2017). The adoption of these features enhances recycling and remanufacturing performance (Kouhizadeh et al. 2020; Yu et al. 2021a). Literature has also indicated that the adoption of BCT facilitates firm's strategies effectively and contemporary issues in CE (Negri et al. 2021; Kouhizadeh et al. 2021) such as RRP, customization, and flexibility in production operations (de Sousa Jabbour et al. 2018). Researchers have indicated ADT and CE as the future of organization (Fatorachian and Kazemi 2018; Zhong et al. 2017).

BCT and business analytics have distinctive roles in various applications, for instance, BCT features aid in data storage, smart contracts, and protection (Zheng et al. 2018) while business analytics helped in analyzing data and enable firms to make future decisions on the bases of past trends (Duan and Xiong 2015). BCT also facilitates the whole SC process by providing transparency, integration, and data security, which helped in smooth flow of product and material (Umar et al. 2022; Kouhizadeh et al. 2020; Alexandris et al. 2018). Khan et al. (2021a) also indicated that BCT prevents double-spending, data tempering, and false ownership through ensuring continuous data flow. Prevention of fraudulent activities in SC operations help firm in improving efficiency and reducing cost (Chen 2018). Keeping in view the above discussion, it can be stated that the adoption of BCT and business analytics provide firms with various benefits and facilitate RRP. Thus we hypothesize that:

H1: ADT has a positive role in adoption of RRP.

2.2 Remanufacturing and recycling practices and firm performance

RRP are the part of CE (Kerin and Pham 2019). The remanufacturing of products provide firms with the opportunity to improve the efficiency of resources, support sustainable production, and lessen waste (Matsumoto et al. 2021; Liu and Bai 2014). It is also known as regenerative approach as it focused on controlling production loops; consequently, reducing wastage and adverse emission and cost (Geissdoerfer et al. 2017). Basically, RRP in production operations ensure maximum functionality of product and material (Khan et al. 2021a), thus enhancing the resource utilization and firms operational performance (Sehnem et al. 2019). Adopting RRP also provide enterprises with environmental and economic benefit by facilitating effective utilization of resources, waste management, and conservation of resources (Mangla et al. 2018). Researchers believe that the traditional method of production was the core reason for ecological deterioration (Bag and Pretorius 2020). Thus the implementation of green and RRP can substantially reduce adverse emission and wastage, which aid firms in achieving triple bottom line ideology (Umar et al. 2021a). RRP also help enterprises in efficient utilization of resources and energy that subsequently improve firm performance (Morais and Silvestre 2018).

Researchers have affirmed that RRP can achieve sustainable goals, as it can significantly lessen wastage and adverse emission, thus improving firm's performance (Korhonen et al. 2018; Khan et al. 2021b). Literature has also indicated that CE and RRP conserve resources without upsetting consumption (Oskam et al. 2021). Although the empirical research works provide evidence that the adoption of green and RRP provide firms with economic benefit (Danese et al. 2019; Abdul-Hamid et al. 2020; Khan et al. 2022). However, scholars have also asserted that the implementation of green/RRP cause stress on financial health of the firm (Zhu et al. 2017). Thus we hypothesize that:

H2: RRP have a positive impact on AFP.

2.3 Covid-19, remanufacturing and recycling practices and firm performance

Before the spread of COD-19, CE models were thought to be the economic approaches, but this pandemic has altered the approach and insisted firms take initiatives towards CE to challenge economy's linear model (Wuyts et al. 2020). The COD-19 pandemic also indicated that enterprises across the globe were working to get the economic benefit by taking into account traditional models (Yu et al. 2021a, b; Piscitelli et al. 2020). That is why, during pandemic circumstances, when the economic activities were halted, environmental sustainability across the globe improved (Khan et al. 2021a). In this regard, researchers had examined the air index of China and found improvement in air index of China as compared to earlier (Liu et al. 2020). On the other hand, pandemic had caused economic losses to firms but was

the opportunity for firms to fully adopt the CE model as it helped improve product delivery services using minimum resources (Hossain 2021; Umar et al. 2021b).

Researchers have also stated that COD-19 has caused disruption in production processes and consumption patterns and become the opportunity for firms to improve their performance through circular practices facilitated through ADT (Nandi et al. 2021; Ibn-Mohammed et al. 2021). Scholars have also indicated that this pandemic has prompted enterprises to develop and design new products by efficiently managing waste (Umar et al. 2021b). Moreover, Wicker et al. (2021) have illustrated that due to COD-19 lockdown measures energy sector faced substantial contraction, but the renewable energy consumption, specifically renewable bioenergy increased as it has the circular approach and has zero emission. On the other hand, lockdown policies had caused disruption in shipping recycling SC in various countries especially in Pakistan, Bangladesh, and India due to the unavailability of the workforce to recycle parts for reuse, resulted in enormous amount of losses to firms subsequently affected the firm's performance negatively (Rahman et al. 2021). Thus we hypothesize that:

H3: COD-19 positively moderates the effect of ADT on RRP.
H4: COD-19 negatively moderates the effect of RRP on AFP.

3 Research methodology

The aim behind choosing RRP is to eradicate the externalities of business operations and enhance automobile firms' environmental sustainability. For this purpose, cross-sectional data were collected from Malaysian and Chinese automobile firms through online survey. For the collection of data, 200 questionnaires were emailed through Facebook, Whatsapp, Linkedin, Wechat messenger, Instagram, and emails. The data was collected during the month of June, July, August, and September of 2020 on 5 point Likert scale (1 = strongly disagree to 5 = strongly agree). From the distributed questionnaires, only 147 were received back, among which 13 were not properly filled, which were excluded from the sample. While the remaining 134 questionnaires were added to the sample size for the testing of hypotheses. Figure 1 illustrates the theoretical framework of the current study.

The current study utilized structural equation modeling (SEM) as it is the most powerful technique for the testing of hypotheses (Afthanorhan et al. 2020) examining the complex link among the latent constructs (Hair et al. 2006) and can estimate latent variable via observed variable. In SEM, Partial Least Square structural equation modeling (PLS-SEM)

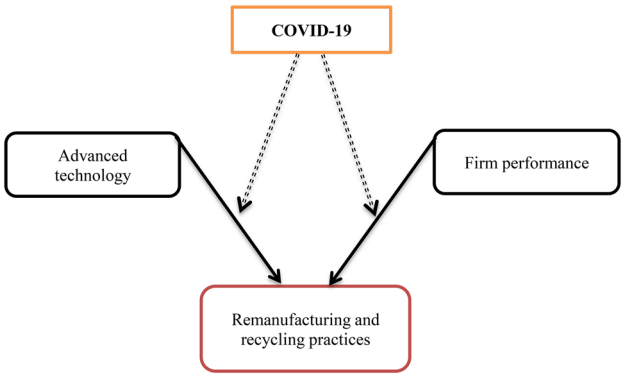

Fig. 1 Theoretical framework

and co-variance based structural equation modeling (CB-SEM) are used. The present research work utilized CB-SEM as it is more suitable for the validation and testing of hypotheses (Mohamad et al. 2019). This technique analyzes the mean of each construct and covariance structure. The basis for fitting using CB-SEM is to measure the covariance matrix precisely. This technique has different indices such as GFI, CFI, and RMSEA which indicate the model good fitness, these indices are not available in PLS-SEM. This technique is known as parametric statistics and is better than non-parametric approach (Mohamad et al. 2019). Table 2 illustrates the demographic details.

4 Results and discussion

To determine the convergent validity, this study assessed the value of outer loading and AVE (see Table 3). All the values loaded high on their respective constructs and the values of AVE are above the threshold value of 0.5 (Hair et al. 2019) subsequently, meet the validity and reliability criteria. Also, the values of CR and Cronbach alpha and satisfy the recommended criteria of 0.7 (Sarstedt and Cheah 2019; Hair et al. 2020). Moreover, the values in Table 4 confirmed discriminant validity as the AVE values square root are greater than its correlation value with any other variables.

The values in Table 5 illustrate model fitness results, in which all the values meet the fit indices criteria, subsequently, indicating that our model is good fit.

The findings of the current study in Table 6 illustrate that ADT influence RRP ($\beta = 0.413$, $p < 0.05$). Similarly, Bai et al. (2020) also illustrated that emerging technologies play a crucial role in upgrading and enhancing sustainable practices/domains through information sharing, greater visibility, and strengthening the relationship among SC partners. They also elaborated that real time availability of accurate data through using BCT helped in reducing carbon footprint from

Table 2 Demographical details

Particulars	Description	Numbers	Percentage
Gender	Male	92	68.66%
	Female	42	31.34%
Total		**134**	**100%**
Age	20–29 years	19	14.18%
	30–39 years	74	55.22%
	40–49 years	27	20.15%
	Above 50 years	14	10.45%
Total		**134**	**100%**
Qualification	High school and below	43	32.09%
	Undergraduate	62	46.27%
	Postgraduate	29	21.64%
Total		**134**	**100%**
Management levels	Top level management	26	19.40%
	Middle-level management	93	69.40%
	Lower level management	15	11.19%
Total		**134**	**100%**
Job experience	Less than 5 years	41	30.60%
	6–9 years	59	44.03%
	10–14 years	21	15.67%
	Above 15 years	13	9.70%
Total		**134**	**100%**

SC operations. For instance, Bumble Bee Foods in 2017 adopted BCT, customers can get easily access to the history of product manufacturing through scanning QRcode. This effective sharing of information sharing among SC operations significantly reduces fraudulent activities, counterfeit and builds strong customers trust on product (Lim et al. 2019).

BCT also provides firms with smart contract facility, which enhances efficiency and helped in reducing cost of procurement processes (Lähdeaho and Hilmola 2020; Hoek 2019). Moreover, Shojaei et al. (2021) studied the role of BCT in CE practices on a case study scenario, the researchers elaborated that BCT enabled firms to do planning regarding recycling and remanufacturing of material and provide transparency and traceability in product, material, and energy flow. They are also of the view that this technology is more suitable in implementation of RRP. Bergendahl et al. (2018) also focused on technological aspect such as integration, digitization and automation in implementation of CE practices. The researchers also illustrated that the implementation of BCT not only facilitate CE practices, can also aid in connection among smart cities through real time sharing of information (Shojaei et al. 2021).

The outcome also illustrates that RRP have a substantial impact on AFP ($\beta = 0.297$, $p < 0.05$). Similarly, Moric et al. (2020) examined the impact of circular practices on enterprise performance and illustrated that the

Table 3 Instrument reliability and validity

Factors	Abbreviations	Items	Factor loading ranges	Cronbach's Alpha	AVE	CR
COVID-19 pandemic	COD-19	3	0.676–0.882	0.872	0.659	0.823
Adoption of advanced technology	ADT	6	0.746–0.891	0.910	0.641	0.855
Remanufacturing & recycling practices	RRP	5	0.598–0.821	0.813	0.571	0.738
Automobile firm performance	AFP	4	0.708–0.943	0.922	0.681	0.881

Table 4 Discriminant validity analysis

Factors	COD-19	ADT	RRP	AFP	Mean	S.D
COD-19	-				3.59	0.629
ADT	0.513**	-			1.99	0.422
RRP	0.414**	0.255*	-		2.55	0.336
AFP	-0.482*	0.502**	0.479***	-	4.57	0.766

***, **, and * indicates the significance at 1%, 5%, and 10% respectively

Table 5 Model fitness results

Fit induces	NNFI	NFI	CFI	GFI	AGFI	TLI	CMIN/DF	RMSEA	SRMR
Criteria	≥0.90	≥0.90	≥0.90	≥0.90	≥0.90	≥0.90	≤3	≤0.08	≤0.08
Measurement model	0.911	0.910	0.913	0.908	0.931	0.941	1.932	0.037	0.027
Structural model	0.931	0.922	0.935	0.911	0.939	0.950	1.253	0.039	0.025

Table 6 Regression analysis

Hypothesis	Paths	Standardized estimate	Results
H1	ADT → RRP	0.413**	Supported
H2	RRP → AFP	0.297***	Supported
Moderation Results of COVID-19			
H3	ADT → RRP	0.327*	Supported
H4	RRP → AFP	0.139	Not supported

***indicate significance at 1%, 5% and 10% respectively

implementation of circular practices provide firms with economic benefit as well as improve their ecological performance. Bhatt et al. (2020) also demonstrated that the increase in organizational performance is linked with CE practices, and the enterprises to have benefited from CE practices, they need to adopt long term circular SC plans. Hussain and Malik (2020) explained that the core objective behind CE practices is to enhance the ecological performance, while firms are only using the logo of CE practices just for marketing purpose and to gain monetary benefit. Furthermore, Heyes et al. (2018) elaborated that the implementation of CE practices helped firms conserve resources and protect the environment. Halkos and Skouloudis (2018) also illustrated that CE practices enabled firms to take responsibility of society and environment along with monetary benefits.

The current study results also depict that COD-19 positively moderates the effect of ADT on RRP ($\beta = 0.327$, $p < 0.05$) while having insignificant moderating effect between RRP and AFP ($\beta = 0.139$, $p > 0.05$). This is concurrent with the study of Khan et al. (2021a, b, c) in which the researchers analyzed the impact of COD-19 on CE practices. They illustrated that although COD-19 was the reason of lockdown across the globe, but it had created a reassuring situation for firms to promote and adopt CE practices, in order to improve their resource consumption. Wuyts et al. (2020) also discussed how COD-19 have pushed various sector to move towards circular strategies, they have also elaborated that the idea of CE become more apparent in healthcare during COD-19 when the supplies for PPEs come to end, this gave immense rise in circular practices to meet the demands in health care sector. Moreover, Ibn-Mohammed et al. (2021) examined the impact of COD-19 on ecosystem and global economy in their study, they have affirmed that the COD-19 was the opportunity for firms to move towards circular practices; also, they elaborated that CE enabled firms to gain balance between profit and environmental harm.

5 Conclusion

The current study investigates the role of ADT in RRP and its impact on AFP. The data for the current study is collected from automobile manufacturing firms located in Malaysian and Chinese territories. The result illustrates that the adoption of ADT have a key role in the adoption of RRP as the adoption of ADT provide firms with analytics techniques, smart contract facility, transparency, and visibility in information flow of SC processes. The outcome also indicates that RRP improve AFP. Moreover, the results also indicated that COD-19 positively moderates the effect of ADT on RRP while having insignificant moderating effect between RRP and AFP. The current research work is expected to enhance our understanding about the application of ADT (blockchain and business analytics) in RRP and improve AFP through development and advancement in green practices and waste management. This study is also a declaration for environmentalists, practicing managers, regulatory bodies, and logisticians to advance and strengthen their environmental legislation through adoption of ADT.

The current study provides managerial implications for managers and policymakers of developing countries. In general, the findings emphasize automobile industry to move towards circular plans and practices and invest more in circular design as it can help firms in improving end of product life management and reduce cost. During interaction with managers and practitioners, it was revealed that Electric Vehicle (EV) market is putting more pressure on batteries SC, which also needs to be focused more on sustainable SC practices. It is also recommended that automobile firms need to invest more in recycling technology which facilitate re-usage of waste with a long-term objective of reducing cost without undermining the products quality. This study also motivates enterprises to inject BCT and use business analytics in operations as it provide them with historic data about their performance, help in evaluation of machines condition, and predict which parts need replacement, subsequently optimizing them for more prolonged use. It is suggested that governmental bodies should provide systematic and long term supporting program, interest free loans, and subsidies for the adoption and implementation of recycling technologies and impose high tax rate, fines and cancel firm's registration and seal them permanently that violate environmental laws. It is also recommended that governmental bodies in emerging countries should lead the implementation of ADT and CE projects in those automobile and other manufacturing firms that have linear economy approach, as it can help in effective implementation of both of these emerging concepts. Moreover, the governmental bodies need to enhance

the span of control of environmental institutions towards implementing CE practices in automobile firms, it can also boost sustainable practices in firms and aid in improving environmental sustainability in the country.

Future researchers can conduct study on different industries and compared their results. This will help in understanding these industries focus and adoption trend of CE practices (remanufacturing and recycling). Future researchers can extend the above mentioned model through adding other circular practices such as circular purchasing and design etc. and test them through employing advanced mathematical modeling and simulations to uncover the underlying phenomena among these variables, doing this will add to the body of knowledge and will enable researchers to come up with robust findings.

Declarations

Conflict of interest statement The authors have no competing interests to declare that are relevant to the content of this article.

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