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Intellectual Capital, Blockchain-driven Supply chain and Sustainable Production: Role of Supply chain mapping

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Abstract – The production and consumption of products are held responsible for most environmental challenges and climatic changes, which adversely affect human lives and compromise the future of generations to come. Sustainable production appears as a strategic route to combat these adversities, the pursuit of which is highly challenging. In this study, we argue that Intellectual capital (IC), featured by human capital, relational capital, and structural capital, can play a dual role in improving the sustainable production of a firm. We put forward that IC contributes to sustainable production directly and indirectly through the adoption of blockchain-driven supply chain management (BCSCM). In this context, the objective of this study is to examine the impact of intellectual capital (IC) on sustainable production. The study also investigates the role of SC mapping and BCSCM in the association between IC and sustainable production. Data were collected from 289 textile firms of Pakistan and Bangladesh with the help of a designed questionnaire. The study employed CB-SEM to examine the modeled relationship. Further, PLS-Multi-group Analysis (MGA) was used for cross-country comparison of the results. The results diverge from the conventional wisdom exhibiting an insignificant direct impact of IC in sustainable production. Nevertheless, the results show a meaningful indirect effect of IC through BCSCM and SC mapping on sustainable production. Results also exhibit a significant direct impact of BCSCM on the sustainable production of a firm. The results call for consideration of IC and BCSCM in improving the sustainability of a firm.

***Keywords*:** Intellectual Capital; Sustainable Production; Role of Industry4.0 based Supply chain; Supply chain mapping

1. Introduction

Industry 4.0 (I4.0), conceived in 2011 as a future business strategy in Germany, is now a hardcore reality, disrupting conventional business processes and market dynamics. It has triggered massive digitalization of manufacturing processes, automating the end-to-end value chains with minimal human interactions (Sprovieri, 2019; Mubarik et al., 2021). Equipped with technologies including Cyber-physical systems (CPS), Industrial Internet of Things (IIoT), autonomous vehicles, cloud and cognitive computing, and many more, it is pushing the business process digitalization and automation to unprecedented levels. Further, I4.0 facilitates the applications of advanced analytics and business-intelligence capabilities, resulting in new forms of human-machine interaction such as advanced robotics and 3-D printing (Baur and Wee, 2015; Khan et al., 2021). These staggering digital advancements are transmuting the traditional supply chains (O'Marah 2017: Mubarik and Naghavi 2020). According to Stank et al., (2019 , p.957). "*If industry observers and scholars are to be believed, we are on the cusp of an age where conventional supply chain processes will soon dramatically change, or alternatively, become completely usurped by electronic information streams*."

In order to amicably adopt the new paradigm, the key challenges faced by the present supply chains need to be well understood. The first challenge among them is sustainable production. Rapidly changing climatic conditions and increased awareness about social and environmental issues have brought sustainable production to the center point (Mahmood and Mubarik 2020; Khan et al., 2021; Mubarik et al., 2021b). Firms are increasingly being pushed both externally and internally to ensure the sustainability of their production processes. Firms are looking for developments in supply chains that can contribute to their sustainable production.

A second critical challenge, intertwined with sustainable production, is related to traceability. It is puzzling to find an appropriate tool(s) available for manufacturers to ensure the sustainability of the production processes. The absence of such tools is creating problems of supply chain visibility in the extended supply chains. It is important for the businesses to have visibility of products in every stage of the supply chain, such as the identity, location, and other tracking information (Ganesan et al., 2016). Blockchain-driven supply chain and supply chain mapping appear to be a natural fit to simultaneously cater to SC traceability and sustainability (Mubashar and Zuraida 2019). Nevertheless, how SC mapping can influence the sustainability of the production process is vague and calls for much-needed research. Likewise, the impacts of blockchain-driven supply chains on sustainable production are inconclusive.

Furthermore, the implementation of blockchain-driven supply chain and supply chain (SC) mapping requires well-integrated organizational processes, strong relationships with stakeholders, and high levels of human capital, collectively known as intellectual capital (IC) (Secundo et al., 2020). Mubarik et al., (2021) argued that IC is an indispensable organizational asset for incorporating technological developments like blockchain-driven supply chain and supply chain mapping. They continued to argue that a firm's strategic initiative may turn into a disastrous situation without a strong IC. Although the fundamental link between IC, technological adoption, and sustainable production is on the whole persuasive, more remains to be understood about its precise nature. Our study attempts to address this issue by refining and extending the understanding of the IC-BCSCM-sustainability paradox.

We draw upon the IC-based view and develop new insights on the role of IC in increasing BCSCM and SC mapping. We argue that IC—*in the form of human capital, relational capital, structural capital*—can play an instrumental role in improving a firm's SC mapping and BC-BSC, enhancing sustainable production of a firm. More specifically, from studies on IC, we construe how human, organizational, and social capital enable organizations to adopt a blockchain-driven supply chain and its impacts on sustainable production thereof. Further, drawing upon dynamic capabilities theory, we argue that SC mapping and BCSCM can be instrumental in increasing sustainable production.

We collected data from 289 firms of 02 South Asian nations, Pakistan and Bangladesh, to empirically examine our argument. In doing so, the study contributes to the literature in at least three ways. First, drawing upon the dynamic capabilities theory and IC-based view, we propose a new framework, modeling the IC, blockchain-driven supply chain, SC mapping, and sustainable production together. Second, the study provides empirical evidence on the role of BCSCM and SC mapping in the association between IC and sustainable production. Thirdly, the study provides empirical evidence on the impact of IC on sustainable production.

The study proceeds with the following structure. Section 2 discusses the literature, including the theoretical exposition and hypotheses development. The methodology is presented in Section 3, covering the data, data collection instrument, and analytical technique. In Section 4, the findings of the study are presented and are discussed in Section 5. Finally, the study concludes by suggesting the implications, limitations, and future research directions in Section 6.

2. Literature Review

2.1 Theoretical Exposition

The study takes its theoretical basis from the Intellectual Capital-based view (ICV) and dynamic capabilities theory (DCT). ICV, according to Reed et al. (2006), asserts that the combination of three dimensions of IC, i.e., human capital, relational capital, and structural capital, leads toward a unique, indivisible resource endowment, which can significantly influence the performance of a firm. ICV is closely linked with Knowledge-Based View (KBV), as both stem from Resource-based view. Nevertheless, both differ in focus as KBV's primary focus is "evaluating the effectiveness of a firm's use of knowledge-management tools as knowledge-generating mechanisms, such as its information technology systems and information management systems" (Reed et al., 2006, p. 869). Whereas the prime focus of ICV is "on the stocks and flows of knowledge capital embedded in an organization and is posited to have direct associations with its financial performance." We argue that sustainable production is an integral part of a firm's performance; hence, IC can profoundly influence it.

We model the blockchain-driven supply chain (BCSCM) by taking the lead from the dynamic capabilities theory. For Teece et al. (1997, p.529), "*The capabilities approach places emphasis on the internal processes that a firm utilizes, as well as how they are deployed and how they will evolve*." For the DCT to sustain long-term competitive advantage, a firm's resources should have the dynamism to encounter the rapidly changing business environment. The development of such dynamic capabilities can help the organization attain performance objectives. We argue that BCSCM is a dynamic capability of an organization, which can play an instrumental role in augmenting the sustainable production of the firm. Likewise, BCSCM also enables firms to attain the dynamic capabilities (e.g., SC mapping) to effectively integrate suppliers, customers, and other related players in the supply chain. Drawing on dynamic capabilities and ICV, we propose that BCSCM enhances the capability of the supply chain by enabling SC mapping and creates value for the organization by improving the sustainable production and visibility of a firm. Further, taking the lead from ICV, we argue that IC enables a firm to attain BCSCM and to develop SC mapping capabilities.

2.2 Hypotheses Development

2.2.1 Intellectual capital and sustainable production

Intellectual capital (IC) represents an organization's intangible resources, which can profoundly influence a firm’s sustainable production. It considers the organizational relationships with its suppliers, customers, and employees, the organization’s processes and routines, and technical know-how, expertise, and knowledge rooted in an organization's human resources (Secundo et al., 2017; Mubarik et al., 2021). There is a broad consensus by scholars (e.g. Bontis, 1998; Han and Li 2015; Bontis, 2015; Ahmed et al., 2019; Mahmood and Mubarik 2020; Salvi et al., 2020; Mubarik et al., 2021) on the fact that IC has three major interrelated dimensions namely human capital, relational capital, and structural capital.

Human capital (HC) encapsulates the knowledge, skills, abilities, and resilience of employees of an organization, which can be directly or indirectly instrumental in uplifting organization performance partly or as a whole (Li et al., 2021; Wang et al., 2021). For Mubarik et al. (2021, p.3), “human capital [is] the knowledge, skills, multi-tasking ability, commitment, engagement, attitude, experience, intelligence, and creativity of employees of an organization”. *Relational capital (RC)* is defined as the sum of an organization's relationship with its stakeholders. In other words, it is the associations and collaborations of an organization with its customers, suppliers, and other stakeholders. *Structural capital (SC) refers to as the organization processes, routines, and* non-human knowledge rooted in the organizational processes and data basis. The knowledge remains with the organization, unlike human capital (Ahmed et al., 2019; Mubarik et al., 2019). For Mubarik et al. (2021, p.3), “SC represents the institutional memory and codified knowledge base of the firm even when employees come and go.” Put together, HC, RC, and SCL are three important constituents that form the intellectual capital of a firm.

Researchers (e.g. Bontis 1998; Mahmood and Mubarik, 2021) argue that all three cords of IC play a crucial role in improving sustainable production. Some of the researchers, clubbing sustainable production as pert of the normal firm performance, conclude IC as the major factor influencing firm performance. In view of such scholars, uplifting IC directly or indirectly contributes to sustainable production. Nevertheless, substituting sustainable production with performance may not be entirely true as in some of the cases, conventional performance parameters could be altogether different and, in some cases, even conflicting to the concept of sustainable production. Therefore, according to Khalique et al. (2020), IC's impact on performance may not be generalized to the other performance aspects like sustainable production. According to Mubarik et al., (2021), sustainable production considers the systems and processes that are green, energy-efficient, and economical. It can be taken as the subset of corporate sustainability (Ahmed et al., 2021).

The notion of sustainable production was introduced at United Nations Conference on Environment and Development in 1992. According to US-EPA(2021, p.1), "Sustainable manufacturing [production] is the creation of manufactured products through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources." US-Environmental Protection Agency (US-EPA) further claims that sustainable production can significantly improve the safety of the employees, products, and community. It is well interlinked with the concept of sustainable development. Primary resource conservation (energy and material use), greenness (environment sinks), social justice, community development, and economic performance are important facets of sustainable development. According to Veleva and Ellenbecker (2001), sustainable production requires work on six major facets, namely i) usage of material and energy, ii) natural environment, iii) community development and societal justice, iv) financial/economic performance, v) employees and vi) products. These parameters are closely linked with the triple bottom lines (TBL) model of the helix, where the people, planet, and profit are considered as the center of an organization. For the sake of this study, we are taking a company's environmental performance, economic performance, and social performance as major indicators to gauge sustainable production.

Although a clear-cut demonstration of the relationship between IC and sustainable production may not be available in the literature, several studies indirectly highlight the impact of IC on the various aspects of organizational sustainability (Mahmood and Mubarik 2020; Khan et al., 2021). For example, Eisenstat (1996) argued that the development of human capital through effective HR practices directly contributes to the sustainability of an organization. Similarly, Rayner and Morgan (2018) showed a significant impact of human capital—measured as employees' green behavior—on the knowledge about sustainability.

Regarding the effect of relational capital on sustainability, some studies (e.g., Bansal 2002; Khan et al., 2021; Mubarik et al., 2021) highlighted the instrumental role of structural capital – organizational processes, routines, databases, and systems—in augmenting the sustainability of an organization. Previously, Prajogo and Mc Dermott (2011) also showed the impacts of structural capital in improving environmental compliance. Further, studies (e.g., Chung et al., 2012; Khan et al., 2020) demonstrated a significant role of relational capital in sustainability performance, including sustainable production. Against this backdrop, we draw the following hypothesis:

Hypothesis 1: IC positively contributes to sustainable production.

2.2.2 Intellectual Capital and BCSCM

We also argue that a strong intellectual capital can play a significant role in adopting and implementing the blockchain-driven supply chain, which can further influence sustainable production. Starting from the human capital, the first cord of IC, it is argued that high quality human capital—*equipped with employees with right experience, skills, and understanding of the customer market*—have higher capability to identify, adopt and implement the technological developments taking place in the business environment (Subramaniam and Youndt, 2005; Mubarik et al., 2018). Critical knowledge and information about technological processes learned from supply chain partners can be applied to manufacturing processes more effectively and efficiently with a high level of HC. Further, firms with high-quality human capital can have a higher tendency to learn the technological developments from their suppliers and customers. BCSCM, being the key technological development, can be better understood and adopted by firms possessing high-quality human capital.

Relational capital, represented by the firm's relationship with its stakeholders, can also play a profound role in understanding and adopting block chain-based supply chain management. A firm having collaborative relationships with external stakeholders has more access to the knowledge embedded in the external networks. Such knowledge can be related to the process technologies like BCSCM or product or network innovation. In short, the stronger relational capital enhances access to the latest knowledge and helps in adopting it. The technological knowledge obtained from external resources could be exploited by making it part of the organization routines. A strong structural capital can help a firm assimilate and institutionalize technological developments effectively and efficiently (Mahmood and Mubarik 2020; Mubarik et al., 2021).

Hypothesis 2a: IC positively contributes to the application of blockchain-based supply chain management

2.2.3 Blockchain-based Supply Chain Management and Sustainable production (SP)

Blockchain has appeared as a cutting-edge technology has enormous potential to improve the performance of supply chain management. Unlike other technologies, block technology uses a decentralized database for the storage of information. According to Laabs and Dumanovic(2020, p.144), "a blockchain is a type of distributed ledger system holding records that are consolidated into timestamped blocks, which are automatically replicated and shared among the members of a blockchain network." It stores data in distributed ledger among a particular group of participants. An individual member can not change the data. This makes blockchain ledger trustworthy. Further, data stored on BCT is immutable as the record of complete transaction history is maintained on the blockchain ledgers. This technology has immense potential to transform the conventional SC to a high-performing blockchain-based supply chain (BCSCM). Primarily, it can be used for SC traceability, transparency, verifiability, and security. The unique architecture of blockchain also helps to improve the efficiency of the transaction. BCSCM can influence sustainable production as the implementation of BC greatly help firm to realize the knowledge and information sharing among the supply chain partners. The improved sharing of information helps the firm identify the waste in the supply chain processes and reduce the cost of production (Yeoh, 2017). One of the major challenges to incorporating sustainable production is information transparency, security and traceability. The decentralized databases, having distributed ledger technology, enable blockchain-driven supply chains to be comparatively safer, trustworthy, and traceable (Orji et al., 2020). They can also play a key role in detecting and preventing any unsustainable process (s) and practice(s) in the supply chain, which is the very essence of SC mapping (Mackey and Nayyar, 2017). For Mubarik et al. (2021), BCSCM can profoundly influence the sustainability of a firm's production as it develops a firm's capability to better monitor and evaluates the sustainability of its business processes. According to Xue et al. (2020), "blockchain is a cutting-edge technology that can transform and remodel the relationships between all members of the supply chain system". They further mention, *"The application of blockchain in the supply chain is still in the trial stage. But practical facts tell us that the use of blockchain in the supply chain will have a significant impact on its operation and will reshape the relationship among the members"* (p.2). Based on the literature discussed above, we draw the following hypothesis:

Hypothesis 2b: The application of BCSCM contributes to sustainable production.

2.2.4 IC and SC mapping

SC mapping refers to *"the process of engaging across companies and suppliers to document the exact source of every material, every process and every shipment involved in bringing goods to market"* (Ivanov, and Dolgui, 2020). It represents the supply network relationships, flows, and dynamics in a simplified yet realistic manner by capturing the essence of the environment in which the supply chain operates. SC mapping assists an organization in visualizing "*the network that connects the business to its suppliers and its downstream customers and allows the identification of problematic areas and support process decisions*." SC mapping is a stringent and challenging process that requires close collaboration with internal and external stakeholders and demands a high level of human knowledge, skill, and expertise—human capital— to drive it. SC mapping requires employees to have a solid knowledge of a firm's supply chain processes and how they are linked with the upstream and downstream partners (Mubarik et al., 2021). SC mapping greatly depends on how a firm closely interacts with its suppliers and customers— relational capital. SC mapping projects could not succeed due to the weak relational capital of a firm (Mubarik et al.,2021; Ali et al., 2021). According to Khan et al. (2020), an organization with a stronger and well-documented process has higher chances of mapping its supply chain. As a matter of fact, SC mapping efforts can not be initiated without having standardized supply chain processes and routines. The above literature reveals the connectivity of all three cords of IC i.e. human, relational, and structural capital with SC mapping and allows us to draw the following hypothesis:

Hypothesis 3a: IC positively contributes to the SC mapping

2.2.5 SC Mapping and Sustainable Production

In order to ensure the sustainability of the supply chain processes, they must have traceability, visibility and verifiability. SC mapping can make the processes traceable by linking the processes with technologies and providing a stand-in of the actual environment. Researchers (e.g. Cooper et al., 1997; Christopher & Lee, 2004; Childerhouse & Towill 2006; Carvalho and Machado 2007; Doorey, 2011; Achilles, 2013; Barros et al., 2011; Choi et al., 2020) mention that SC mapping improves the visibility of the processes by providing the real-time data from the various interface points (Mobashar et al., 2020). It also helps to ensure that trust exists among the supply chain partners as information shared could be verified through distributed ledgers. In contrast, an ill-mapped supply chain can reduce the extent of information sharing and can result in unsustainable production. For Mubarik et al., (2021, p.15), "it is important to note that SC mapping cannot only be effective in adopting SC resilience, sustainability, and cleaner production but also play a very instrumental role in controlling the supply chain losses and chaos. The case of Tesco is a stunning example in this regard. In 2013, the company lost nearly 300 million euros when horse meat was found in beef products at some of its stores. The complexity of its food supply chain, having various layers of suppliers, made it extremely challenging for Tesco to identify and separate the origin of the horse meat". SC mapping in this regard can help the firm to cope-up with such situations. Based upon the above discussion, we draw the following hypothesis.

Hypothesis3b: SC mapping improves sustainable production.

Based upon the above discussion, we have derived a conceptual framework of the study as exhibited in Figure 1. It provides a snapshot of the hypotheses of the study. Figure 1 demonstrates the mediating roles of Supply Chain Mapping (H3a and H3b) and BlockChain Based Supply Chain Management (H2a and H2b) in the association between IC and sustainable production. Likewise, it is also reflecting the direct impact of IC on sustainable production (H1).

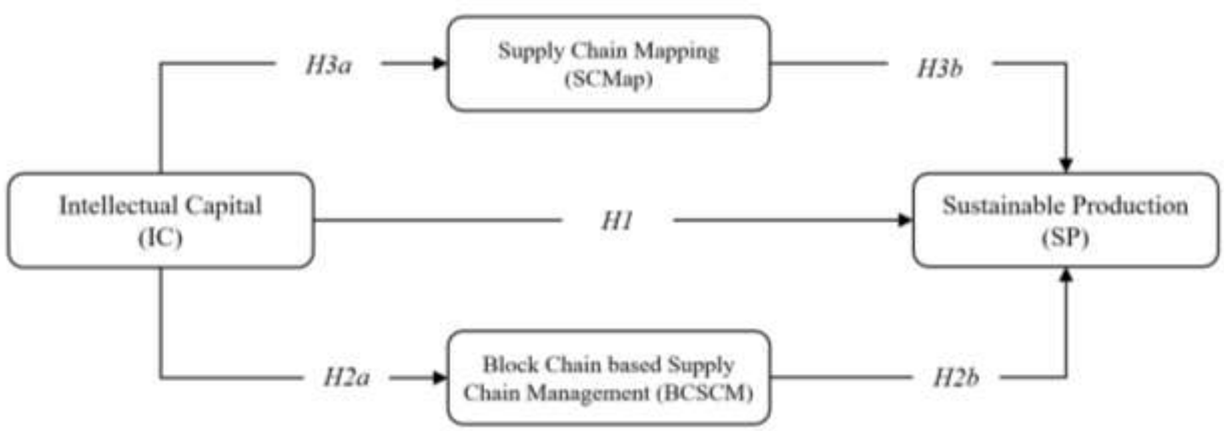

Figure 1: Conceptual Framework

3. Methodology

3.1 Data

Data were collected from 289 textile firms from Pakistan and Bangladesh. The Textile sector in Pakistan is one of the major contributors to the country's GDP and exports. This sector also falls among the top 10 leading exporters of the world. The majority of the textile factories in Pakistan are located in Karachi, Lahore, and Faisalabad. Likewise, Bangladesh's textile sector is a major contributor to the country's export and employment and is considered the backbone of the country's economy.

Data were collected from June 2019 to January 2020. Initially, it was planned to collect data from June 2019 to May 2020 from at least 300 firms for each country. However, due to the COVID, data collection was stopped in the month of January 2020. A total of 800 firms (400 from each country) were selected for the data collection and were sent the questionnaire through email. A total of 160 firms responded to the questionnaire from Pakistan, among which 08 questionnaires were incomplete. After excluding the incomplete questionnaires, the total number of responses from Pakistan was 152. From Bangladesh, we received 143 filled questionnaires; however, six questionnaires were incomplete/wrongly filled and were excluded from the final count. Hence, a total of 137 complete responses were received from Bangladesh. The total sample of 289 questionnaires were processed for analysis.

3.2 Instrumentation

A close-ended questionnaire was developed using a 5-Point Likert scale. All the constructs were adopted from the previous studies. The details of the construct are exhibited in Table 1. The construct of IC was adopted from Mubarik et al. (2021). They recomposed the construct by taking dimensions from various studies. Further, the construct of BCSCM was adopted from Mobashar et al. (2020).

Table 1: Constructs and their Sources

SC Mapping	Upstream Mapping Midstream Mapping Downstream Mapping	Subramaniam and Youndt (2005); Ahmed et al., (2019); Wang et al., (2019); Al-Jinini et al., (2018)
BCSCM	Information Transparency Data and Information Immutability Smart Contract	Kim and Shin (2019)

Sustainable Production	Environmental Social Economic	Veleva and Ellenbecker (2001); Mubarik et al. (2021)
Intellectual Capital	Human Capital Structural Capital Relational Capital	Mubarik et al. (2021)

3.3 Analytical technique: Covariance Based -SEM (CB-SEM)

The study employed covariance based-structural equation modeling (CB-SEM) to estimate the modeled relationships. The CB-SEM is considered the most suitable approach for theory testing. This approach is employed in two steps. In the first step, measurement models internal consistency, reliability, validity (convergent and discriminant), and fitness (GFI, CFI, RMSEA) is evaluated. After confirmation of the measurement model's validity, reliability and fairness, path analysis is done to test the hypotheses of the study. It is important to note that CB-SEM does not allow to compare the groups based on the observed heterogeneity. Therefore, to compare the difference by country, we employed PLS-MGA (Partial Least Square-Multi Group Analysis)

4. Findings

4.1 Respondents demography

Data from 289 textile firms at Pakistan and Bangladesh were collected for the analysis. Table 2 below exhibits the brief demography of respondents. Medium firms constitute 56 % of the total sample whereas large firms constitute 44%, followed by firms aged 20 years or above(30%). Further, firms with an average age between 11-19 years were highest in the sample with 44% percent of the total. Interestingly, around 19% of the firms were found to have foreign ownership whereas 42% of the firms had joint ownership. Some of the firms were owned by expatriate Pakistanis and/or Bangladeshi, who have claimed the nationality of other countries. Demography of the respondent's firms shows a fairly equal distribution of the sample size by country, age, size, and ownership.

Table 2: Profile of Respondent Firms

Size	***Pakistan***	***Bangladesh***	***Total***	**%**
Medium*	87	76	163	56%
Large**	65	61	126	44%
Firm Age(years)				

1 to 10	33	42	75	26%
11 to 19	67	59	126	44%
>20	52	36	88	30%
Ownership				
Foreign	21	34	55	19%
Local	89	78	167	58%
Joint	42	25	67	23%

, & show the employment size between 75 to 200 and >200*

4.2 Internal Consistency, Reliability, and Validities of the scales

The first step for employing CB-SEM is to ensure the construct's internal consistency, reliability, and validity using a confirmatory factor analysis approach. Internal consistency of the constructs was assessed by confirming the CR and factor loading values, which should be greater than 0.60 for each construct. The results in Table 3 exhibit that all the constructs have CR values and factor loadings value greater than 0.60. It ensures the internal consistency of all constructs. The reliability of the construct, which measures the extent to which a construct could be dependable, is gauged by checking the CB alpha value. Results in Table 3, depict that value of CB alpha values of all constructs are greater than 0.70, confirming the reliability of all the constructs.

Further, validity is gauged from two aspects i.e., convergent validity and discriminant validity. The convergent validity is gauged by computing the AVE values of each construct, which should be greater than 0.50. Results show that all the constructs of this study possess AVE values greater than 0.50, thus confirming the convergent validity. The discriminant validity of the constructs was checked by employing the Fornell-Larcker criteria, which compares the square rooted values of AVE with inter-construct correlation. As exhibited in Table 4, the square rooted AVE values are greater than the inter-construct correlation. It confirms the discriminant validity of the constructs. Further, the fitness of all measurement models (constructs) were ascertained from three aspects i.e., parsimonious, incremental, and absolute, using the values of CFI, GFI, RMSEA, and PNFI. The values of CFI, GFI, and PNFI are greater than 0.80, and the values of RMSEA for all constructs are lower than 0.08. It reflects the satisfactory fitness of all the measurement models.

After confirming the consistency, reliability, validity, and fitness of all measurement models, the subsequent section construes the results of path analysis.

Table 3: Reliability, Validity and Fitness

Construct	Sub-construct	Convergent Validity and Reliability				Model Fitness			
		AVE	CR	CB alpha	Loadings	CFI	GFI	RMSEA	PNFI
Supply Chain Mapping	Upstream Mapping Midstream Mapping Downstream Mapping	0.51	0.89	0.78	*Floats between 0.67 to 0.89. Items deleted: USM1, USM2 DSM4*	0.89	0.91	0.07	0.82
BCSCM	Information Transparency Data and Information Immutability Smart Contract	0.53	0.88	0.81	*Between 0.81 to 0.69 Items deleted: DI 2*	0.94	0.92	0.041	0.85
Sustainable Production	Environmental Social Economic	0.52	0.79	0.91	*Between 0.89 to 0.72 Items deleted: ESP 1, SSP 2, EES 2*	0.88	0.87	0.05	0.83
Intellectual Capital	Human Capital Structural Capital Relational Capital	0.51	0.82	0.85	*Between 0.68 to 0.82 Items: deleted: HC1, SC4, RC3*	0.94	0.92	0.078	0.81

Note: Acceptable threshold value of factor loading is 0.50 subject to the value of AVE>0.50.
Threshold values of AVE, CR, and CB alpha are 0.50.060, 0.70 respectively.
The acceptable threshold values of CFI, GFI, and PNFI is 0.80. Whereas the upper acceptable value of RMSEA is 0.08

Table 4: Fornell-Larcker Criteria

	SCMap	BCSCM	SP	IC
Supply Chain Mapping (SCMap)	***0.71***			
BCSCM	0.54	***0.73***		
Sustainable Production (SP)	0.49	0.24	***0.72***	
Intellectual Capital (IC)	0.31	0.37	0.41	***0.71***

4.3 Path Analysis

The estimated model for all firms appears in Figure 2. The complete results of the path analysis are exhibited in Table 5. Before explaining the individual hypotheses, it is essential to explain the overall model fit, its predictive relevance and the significance of the modeled variables. Starting from the value of adjusted R-square, which shows that a considerable variation (53%) in sustainable production is being explained by SC mapping and IC. We also computed Q-square and F-square values of the model using the same mathematical equation used in PLS-SEM. Square values show the high predicted relevance of the model. Likewise, f square values—*measurement of variance explains each exogenous variable in the models*—show the considerable contribution of each variable in the model. Putting together, the results of adjusted R-square, Q-square, and f-square confirm the model robustness, predictive relevance, and significance of individual variables. It enables us to proceed with the hypotheses testing.

First, the path relationship tests the impact of IC on sustainable production in the aggregate sample and then by country. The results reveal a highly significant and large impact of IC on sustainable production in the overall sample (*β 0.41, t-value 2.16*) and in the country-wise analysis [Pakistan *β 0.23, t-value 2.27*; Bangladesh *β 0.37, t-value 4.25*]. The PLS-MGA *(p-value 0.125)* results do not reflect any difference between Pakistan and Bangladesh results, thus confirming the stability of the relationship across the country. These results provide significant support to accept the first hypothesis of the study that denotes a significant role of IC in improving sustainable production.

The study's second hypothesis is the significant and positive mediating role of the application blockchain-driven supply chain (BCSCM) in the juxtaposition of IC and sustainable production. The overarching argument is that IC helps in the effective and efficient adoption of BCSCM, which further significantly influences sustainable production. The results of H2a *(β 0.37, t-value 3.67)* in the aggregate sample support the positive impact of IC on BCSCM. Likewise, H2b is also supported by results *(β 0.29, t-value 2.98)*, confirming the significant impact of BCSCM on Sustainable Production. The results are stable in inter-country comparison, and MGA results do not reveal any significant difference in H2a *(0.062)* and H2b *(p-value 0.091)*.

The third hypothesis of the study models the mediating role of SC mapping in the association between IC and sustainable production. Our results depict a significant impact of IC on SC mapping at 5% (*β 0.31, t-value 4.54) at 5 %*. Likewise, the results also show a significant positive impact of SC mapping on sustainable production *(β 0.42, t-value 3.43)*. These results support H3a and H3b, confirming an SC mapping as a mediator in the association between IC and sustainable production. It implies that IC improves the SC mapping, which further improves sustainable production. The results are stable in country-wise comparison with marginal difference in the coefficient values. The MGA results have also supported the same, which does not reveal any statistically significant difference in the inter-country results (*p-value 0.431; 0.74*). In condensed form, all three major hypotheses of the study have been supported in the aggregate sample and in country-wise comparison, as exhibited in Table 4.

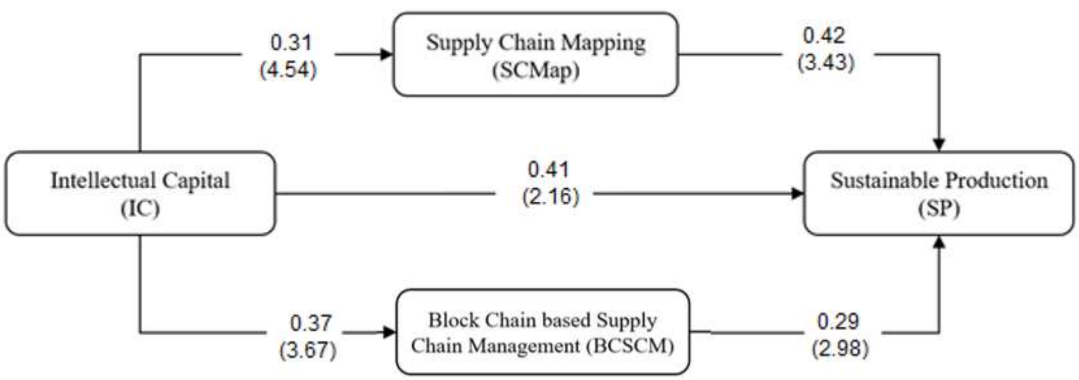

Figure 2: Estimated Model (Overall)

Table 5: Path Analysis

Hypothesis	Path	Overall		Pakistan		Bangladesh		Pak vs.BD
		β-value	t-value	β-value	t-value	β-value	t-value	P-value
H1	IC→ SP	0.41**	2.16	0.23**	2.27	0.37**	4.25	0.125
H2a	IC→ BCSCM	0.37***	3.67	0.19***	4.08	0.29**	2.99	0.091
H2b	BCSCM → SP	0.29**	2.98	0.31***	5.19	0.18**	5.01	0.062
H3a	IC → SC Mapping	0.31***	4.54	0.22***	3.56	0.39***	3.86	0.431
H3b	SC Mapping → SP	0.42***	3.43	0.38***	4.54	0.44***	4.91	0.74
Adj R square		0.53						
Q-Square		0.28						
f-square		0.45						

**** and ** show the rejection of null hypothesis at 1% and 5% respectively*

Table 6: Hypotheses testing

	Hypothesis	Decision
H1	IC positively contributes to the sustainable production.	Supported
H2	SC mapping positively mediates the relationship between IC and sustainable production	Supported
H3	BCSCM positively mediates the relationship between IC and sustainable production	Supported

5. Discussion

The findings of the study illustrate overwhelming support to all three hypotheses, revealing the direct and indirect impact of IC on sustainable production. Likewise, results also support the significant mediating role of BCSCM and SC mapping in the association of IC and Sustainable Production. The results on the impact of IC on Sustainable production are found to be consistent with the Mubarik et al. (2021), Mahmood and Mubarik (2020) and Khan et al. (2021). These studies consider IC as a precursor for incorporating sustainability in the organizational processes, including production processes. Ahmed et al. (2020) construed that IC plays a significant role in increasing an organization's commitment to the environment, community welfare, employee health, and safety. Likewise, Khan et al. (2021) argued that firms with higher levels of IC could have comparatively higher levels of sustainability in the production processes. A higher level of IC implies a higher level of human capital, relational capital, and structural capital. Employees with a higher level of human capital are considered more aware of the triple bottom lines, i.e., economic, social, and environmental performance. They tend to be more careful about the sustainability of their actions (Mubarik and Naghavi, 2020). It has been further supported by Khan et al. (2021), who argued that a higher level of human capital help incorporate sustainability into the production processes of organizations. Yuslize et al. (2019, p. 30) mentioned IC as knowledge and argued, *"knowledge is an asset that can become a unique source of competitiveness among competitors and an important contributor to cleaner production strategies"*.

The findings on the role of BCSCM also concur with the studies of Saberi et al. (2019), Wang et al. (2019), Mubarik et al. (2019), and Mubarik et al. (2021b). For Wang et al. (2019, p. 1), "intellectual capital efficiency (ICE) and its sub-dimensions (i.e., human capital efficiency, organizational capital efficiency and capital employed efficiency (CEE)) have significantly positive impacts on dynamic technology capability." They construed that IC can be instrumental in acquiring and implementing the latest process technologies, e.g., blockchain technology (Wang et al., 2019). Given that blockchain technologies can enhance traceability and improve integrations, it can significantly improve the sustainability of production (Mahmood and Mubarik 2020; Mubarik et al., 2021). In a nutshell, the literature supports the fact that blockchain technology positively reinforces the impact of IC on sustainable production.

Literature on the role of SC mapping in the association of IC and sustainable production is scant; thus, it is challenging to compare and contrast our results with it explicitly. Nevertheless, a recent study by Mubarik et al. (2021) highlights an influential role of SC mapping in improving sustainable production. An effectively mapped supply chain helps a firm zoom into its business processes to visualize unsustainable business processes. This further leads toward the replacement or enhanced such processes to make them more sustainable. Likewise, SC mapping improves integration among internal and external stakeholders, reducing the duplication of efforts and suppressing waste. They argued that an effectively mapped supply chain enables a firm to improve the sustainability of its processes. Whereas enabling SC mapping requires the development of IC, an improvement of IC improves BCSCM, which further helps to attain sustainable production.

6. Conclusion, Implications and Limitations

A majority of the production processes emit pollutants into the soil, air and water during the production process and along the entire supply chain. To remedy this situation, production processes need to be transformed towards the "sustainable production" paradigm. Sustainable production aims to ensure that the production of goods conserves resources and preserves the regenerative capacity of the environment. Against this backdrop, the central argument of the paper is the use of IC to build SC mapping and BCSC to improve and sustain production. The study argued that IC plays a key role in the adoption and implementation of BCSCM, which further contributes to sustainable production. Likewise, the study also asserted that IC enables a firm to institute SC mapping, further affecting sustainable production. Following the IC Based View and Dynamic Capitalizes theory, the study hypothesized the direct impact of IC on sustainable production. Despite the critical role of IC both in building SC mapping and improving sustainable production, there is a void of literature on this conception. Present study bridges this gap.

The findings of the study illustrate that IC yield three major benefits to the organization. First, it directly contributes to the sustainable production of a firm. Second, it significantly improves the efficiency and effectiveness of BCSCM. Third, it enhances the visualization and monitoring of the processes across the value chain by enabling supply chain mapping. The findings also reveal that SC mapping plays a phenomenal role in elevating the sustainable production of a firm.

The study has some profound implications for managers. First and foremost is the need for strategic retreat considering the IC-Sustainable production and BCSCM-Sustainable production dyads. The findings reveal that IC can significantly improve the sustainability of production. Nevertheless, it raises questions as to how the IC can be developed and managed to reap its multitude of impacts. Based on our findings, we suggest a three-stage sequential strategy to be adopted in three stages. First is gauging the level of IC to identify where the firm is standing in terms of the strength of its IC. This could be done by adopting the process suggested by Mubarik et al. (2018). The study of Mubarik et al. (2018) demonstrated that the level of intellectual capital could be gauged on a scale of 1 to 5, with 1 being the lowest and 5 the highest. If a firm's IC level is low (less than 3), then the first thing for them to do is to improve the level of its IC to the moderate level for adopting the next strategy. Second, , it must focus on mapping its upstream, midstream and downstream value chain processes. The stronger level of IC will play an instrumental role in mapping the firm's supply chain processes. The SC mapping will also enable the firm to visualize the flow of products and services across the supply chain. It will also help the firm to zoom in on various business processes to analyze their conformance to the sustainability standards. In short, the SC mapping will significantly contribute to sustainable production. This strategy may be labeled as the SC mapping-led sustainable production. Third, once the business processes have been mapped, the firm may opt to adopt the BCSCM. The adoption of BCSCM will contribute to the sustainable production of the firm and improve the effectiveness of its SC mapping. That is why some of the practitioners often argue that the simultaneous adoption of SC mapping and BCSCM can enhance sustainable production. However, keeping in mind the strategic nature of BCSCM and its impacts on the business processes, it is advisable to adopt a sequential rather than simultaneous strategy. The adoption of BCSCM for improving production sustainability may be labeled as " BCSCM-led-sustainable production." Both SC mapping-led-sustainable production and BCSCM-led-sustainable production require a stronger level of intellectual capital.

As in the case of every study, this study has some limitations. However, these limitations provide ample grounds for future research. First, the above recommendation to adopt SC mapping and BCSCM can be one of the strategic approaches. We suggest future research to look into the appropriate strategic routes to capitalize on IC, SC mapping, and BCSCM for attaining sustainable production. Second, the use of cross-sectional design for testing the basic hypotheses of the study is another principal limitation. Using the case study approach and considering the case of firms that have already implemented the SC mapping and BCSCM can provide an in-depth understating of this paradox. Additionally, the case-based approach can play an instrumental role in clarifying SC mapping and BCSCM effects on sustainable production.

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Appendix: Questionnaire

1. Intellectual Capital

a. Human Capital

1. Employees in our company are highly skilled in their respective jobs.
2. Employees in our company are considered among the best people in our industry
3. Employees in our company are experts in their particular jobs and functions
4. Our employees can find simple solutions for more complex problems.
5. Our employees are well-educated compared with their peers in the industry

b. Relational Capital

1. Employees from different departments feel comfortable while calling each other
2. Our employees apply the knowledge leaned from one area of the company to the other area when they face any problem.
3. Our company is keen on developing long-term relationships with its suppliers and customers.
4. We collaborate extensively with external parties (e.g., customers and suppliers) to develop new solutions
5. Customer feedback guides our company activities

c. Structural Capital

1. Much of our company's knowledge is contained in manuals, archives, and databases.
2. We usually follow the sequence of written rules and procedures
3. Our company embeds much of its knowledge and information in structures, systems and processes
4. Our company uses intellectual property rights (patents/registered software, and copyrights)as a way to store knowledge
5. Our company protects knowledge and key information to avoid loss of key people left the company

2. Supply Chain Mapping

a. Upstream Supply Chain

1. We are able to visualize our upstream SC processes, and activities.
2. The mapping of our SC processes depicts geographical relationships with supplier, allowing spatial visualization.
3. Our firm is able to capture the real time information about the products and materials sourced, their quantities, and replenishment lead time.
4. SC mapping provides real time information sharing of suppliers.
5. We are aware of the tier-2 suppliers of the critical components and raw material.
6. We have documented processes for dealing with suppliers.
7. We are able to visualize the real time flow of material from the suppliers.
8. We have a system for real time sharing of information with suppliers.
9. Our SC mapping provides us a simplified representation of our upstream SC by capturing the essence of the environment in which the SC operates.
10. We have mapped the flow of products, and information in the upstream SC.

b. Midstream

1. We have mapped processes showing the flow of material within the company.
2. We can track the flow of goods within our company in real time from one department to other.
3. We have a system of real time sharing of information within the company, across several departments.
4. We can identify the SC processes inefficiencies in real time.
5. Due to the mapping of midstream processes, we can monitor the effectiveness of our SC strategy.
6. The mapping of our SC helps to catalog and distribute key information for survival in a dynamic environment.
7. Our SC mapping alerts our concerned managers to possible constraints in the system.
8. We have mapped the flow of products and information in the midstream SC.

c. Downstream

1. We have mapped the geographical dispersion of our customers.
2. We have mapped the geographical dispersion of our tier-2 customers.
3. We have a system of real time sharing of information with customers.
4. We can visualize the flow of goods from our company to customers' customers.
5. The mapping of our downstream processes plays an essential role in providing guidance in the quantum changes in the downstream SC.
6. We have mapped the flow of products and information in the downstream SC.
7. The mapping of our downstream SC processes permits our company to identify areas for further analysis.

3. Sustainable Production

a. Environmental

1. Products and packaging are designed to be safe and ecologically sound throughout their life cycles; services are designed to be safe and ecologically sound.
2. Wastes and ecologically incompatible byproducts are continuously reduced, eliminated, or recycled
3. Energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends
4. Chemical substances, physical agents, technologies, and work practices that present hazards to human health or the environment are continuously reduced or eliminated
5. Workplaces are designed to minimize or eliminate physical, chemical, biological, and ergonomic hazards

b. Economical

1. Management is committed to an open, participatory process of continuous evaluation and improvement.
2. Work is organized to conserve and enhance the efficiency and creativity of employees
3. Management is committed to focus on the long-term economic performance of the firm

c. Social

1. The continuous development of employees' talents and capacities is a priority of our organization
2. The security and well-being of all employees is a priority
3. The communities around workplaces are respected
4. The communities around workplaces are enhanced economically.

5. The communities around workplace are enhanced socially, culturally and physically.

4. Blockchain based Supply Chain Management

a. Information Transparency

1. Information transparency has become a critical element to maintain a strong partnership
2. Our firm would be willing to make further investment in importing information transparency to facilitate communication with the partner firm
3. "Information transparency" technology is highly applicable to our firm and may be considered to replace the current contractual relationship with a partner.

b. Data and Information Immutability

1. Data and information immutability have become a critical element for maintaining a strong partnership.
2. Data and information immutability ensure that change and removing information on a private or permissioned blockchain requires notifying the network members and follows certain agreements and approval requirements.
3. Our firm can count on the partner to be sincere based on data and information immutability
4. "Data and information immutability" technology is highly applicable to our firm and may be considered to replace the current contractual relationship with a partner.

c. Smart contracts

1. Smart contracts in the form of digital contracts remove human judgment from transactions and rather follow pre-determined conditions including rules and penalties that are agreed upon with a partner
2. Smart contracts have become a critical element to maintaining a strong partnership
3. "Smart contract" technology is highly applicable to our firm and may be considered to replace the current contractual relationship with a partner.

Note: All the items were measures at 5 points Likert scale.