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Digital supply chain management in the COVID-19 crisis: An asset orchestration perspective

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ABSTRACT

Although many firms are actively deploying various digital technology (DT) assets across their supply chains to mitigate the negative impact of the COVID-19 pandemic on operations, whether these DT assets are truly helpful remains unclear. To disentangle this puzzle, we investigate whether firms that have higher levels of DT asset deployment achieve better supply chain performance in the COVID-19 crisis than firms with lower levels. From an asset orchestration perspective, we focus on two dimensions of DT asset deployment: breadth and depth, which reflect the scope and scale of DT assets, respectively. The empirical results from 175 Chinese firms that have deployed DT assets to varying degrees reveal that both the breadth and the depth of DT asset deployment show positive relationships with supply chain visibility. In contrast, the depth but not the breadth of DT asset deployment poses a positive relationship with supply chain agility. Most importantly, high levels of supply chain visibility and supply chain agility were prerequisites for excellent supply chain performance in the COVID-19 crisis. We contribute to the digital supply chain management literature by uncovering the mechanism through which DT asset deployment generates impacts on supply chain performance from an asset orchestration perspective. Our study also assists firms in improving their digital transformation strategies to combat the COVID-19 pandemic.

1. Introduction

The outbreak of COVID-19 generates huge uncertainties in demand and disruption in global supply chains, resulting in delivery delays and shortages of goods (Tietze et al., 2020). For example, some Foxconn facilities in China were forced to close as a result of the Wuhan lockdown, causing Apple to postpone the release of new goods to the market (Xu et al., 2020). To mitigate the negative impact of the COVID-19 pandemic on operations, firms must optimize their supply chains to ensure a certain level of safety stocks and achieve on-time delivery (Choi, 2021). Because digital technologies (DTs), one type of important asset, can theoretically help firms achieve end-to-end transparency, replace those employees who are absent because of COVID-19, predict potential risks, and reduce demand uncertainty (Ivanov et al., 2019), many firms are actively deploying various DT assets across their supply chains (Ivanov, 2020). McKinsey (2020) reports that the COVID-19 crisis has accelerated the digitalization of supply chains and management practices of most firms worldwide by three to four years.

Although firms that have been fast to deploy DT assets seem to gain higher revenues and better stock performance (Borrett, 2021), in the COVID-19 crisis, there is still controversy as to whether the deployment of DT assets does improve performance, especially supply chain performance (Ralston and Blackhurstb, 2020). On the one hand, some scholars reveal that because many firms regard DT assets as the means to protect existing products and markets, rather than to develop new products and markets, they mainly deploy DT assets to address the current issues related to the COVID-19 pandemic, thus ignoring the long-term impact of DT asset deployment on their supply chains (Ketchen and Craighead, 2020). On the other hand, there are significant variations in how different firms deploy their DT assets (Ivanov, 2020).

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For example, most firms tend to deploy simple DT assets, such as desktop productivity tools and software analysis, to optimize their existing information systems, whereas the proportions of deploying some advanced DT assets, such as robotic process automation, and additive manufacturing, are much lower (Deloitte, 2018). Because of such myopic behavior, some scholars believe that deploying DT assets may not always result in improved supply chain performance, particularly facing the challenge of the COVID-19 pandemic (Belhadi et al., 2021). Given the present knowledge gap and the fact that a company's success is mainly determined by the performance of its supply chains (Whitten et al., 2012), we aim to address the following research question: *Do firms that have higher levels of DT asset deployment achieve better supply chain performance in the COVID-19 crisis than firms with lower levels? If so, through what mechanism?*

We primarily develop our arguments based on the asset orchestration perspective because firms seldom employ a single DT asset in their day-to-day supply chain management, but rather a combination of different DT assets (Sirmon and Hitt, 2009). From an asset orchestration perspective, there are two ways to reflect a firm's DT asset deployment: breadth and depth (Sirmon et al., 2011). The former is connected to the scope of DT asset deployment, whereas the latter is associated with the scale of DT asset deployment (Sirmon et al., 2011). Past studies have found that firms with broad and in-depth DT asset deployment are more likely to establish inter-firm partnerships and better integrate with their supply chain partners to complement their organizational practices (Zhang et al., 2016). Because supply chain visibility is related to the information sharing among supply chain partners (Barratt and Oke, 2007), and supply chain agility requires firms to integrate with supply chain partners to quickly respond to market changes (Wamba et al., 2020), we contend that the breadth and depth of DT asset deployment may enhance supply chain visibility and agility, and ultimately promote supply chain performance, that is, to provide end consumers with high-quality products and services in the COVID-19 crisis.

To verify the above possible mechanisms, we survey 175 Chinese firms. There are two main reasons for choosing Chinese firms. First, China is one of the major countries that have responded well to the COVID-19 pandemic (Wang et al., 2020). Hence, a survey of Chinese firms can provide some guidance for companies in other regions. Second, China is the world's second-largest economy and the engine of global manufacturing; moreover, it is vigorously promoting the digitalization of firms (XINHUANET, 2016), and so provides a large pool from which we can select firms with different degrees of DT asset deployment.

We contribute to the digital supply chain management literature in the following three respects. First, we shift the research focus from a specific DT to the overall DT asset deployment of a firm. Thus, the findings help firms re-examine the relationships between DT assets and performance, especially supply chain performance, from an overall perspective. Second, although previous studies have used the resource-based view or dynamic capacity theory to understand the relationship between DT asset deployment and performance (Ardolino et al., 2017; Matarazzo et al., 2021), we offer a fresh view on digital supply chain management from an asset orchestration perspective, thus helping to explain certain discrepancies in prior research. Third, we demonstrate that supply chain visibility and agility are two factors that have directly influenced supply chain performance in the COVID-19 crisis. However, although both the breadth and depth of DT asset deployment show positive relationships with supply chain visibility, only DT asset deployment depth, and not breadth, has a positive relationship with supply chain agility. Hence, these findings help scholars and practitioners to re-examine the DT-enabled supply chain management.

2. Literature review

2.1. Asset orchestration perspective on the deployment of DT assets

Assets, including tangible and intangible forms, refer to the resources that organizations own or control and that are anticipated to bring economic benefits (Helfat and Peteraf, 2003). To reflect how organizations efficiently use and manage assets, scholars have developed the notion of "asset orchestration" (Helfat et al., 2009). In particular, asset orchestration involves two important dimensions: search/selection and configuration/deployment (Sirmon et al., 2007). The search/selection needs managers to identify valuable assets and invest in them, whereas the configuration/deployment requires managers to determine specific market segments or domains in which to engage those investments (Sirmon and Hitt, 2009). Moreover, past studies have identified two types of asset deployment strategies: breadth and depth (Zhang et al., 2016). The former reflects the scope of asset deployment, whereas the latter focuses on the scale of asset deployment (Zhang et al., 2016).

Because DTs aim to create new economic growth by realizing the digital interconnection of people, products, services, and firms (Ritter and Pedersen, 2020), DTs should be important assets of firms. Accordingly, in line with the work of Zhang et al. (2016), in this paper, we consider two dimensions of DT asset deployment. First, the breadth of DT asset deployment evaluates the scope of how firms deploy their DT assets; typically, firms with broader DT asset deployments are more likely to establish inter-firm partnerships (Zhang et al., 2016). The second type is the depth of DT asset deployment, which refers to the scale of how firms use DT assets. Firms with in-depth DT asset deployment may better complement their organizational practices to integrate with their supply chain partners (Zhang et al., 2016).

Most of the existing literature mainly investigates the outcomes of DT asset deployment through the lens of the resource-based view or dynamic capability theory (Lee, 2021; Matarazzo et al., 2021). For example, through the analysis of four cases, Ardolino et al. (2017) find that DT assets, as an operational resource for manufacturers, can transform initial data into valuable information and knowledge, to support service transformation. Through a survey of 281 firms in the United States, Wamba et al. (2020) find that big data analytics, an important asset, posts a positive impact on supply chain agility, supply chain adaptability, cost performance, and operational performance by improving dynamic capabilities. However, neither of the above two theory perspectives fully explain DT asset deployment. In particular, Braganza et al. (2017) argue that using the resource-based view to understand the role of big data is limited because the hardware resources required by big data are not scarce, and the core data used is not rare, and is often mastered by a third party. In other words, in the context of big data, some basic assumptions of the resource-based view may not be satisfied (Braganza et al., 2017). Furthermore, Sirmon et al. (2011) argue that although dynamic capability theory emphasizes a firm's capacity to integrate and reconfigure internal and external capabilities in response to fast environmental change, it overlooks the relevance between a firm's asset selection and deployment. Unlike the resource-based view or dynamic capability theory, the asset orchestration perspective not only explains how firms choose and deploy their assets but also underlines the fact that the efficient use and management of assets are more essential than the assets themselves (Sirmon et al., 2011). Hence, investigating the influence of DT asset deployment on firm performance from an asset orchestration perspective may provide a more comprehensive understanding.

2.2. Supply chain visibility and agility

Supply chain visibility measures whether a firm has access to high-quality information that describes diverse demand and supply elements (Barratt and Oke, 2007), and it involves supply visibility, demand visibility, and market visibility (Williams et al., 2013). The literature has discussed the role of supply chain visibility in reducing transaction uncertainty (Lee et al., 1997), reducing costs caused by being out of stock or, conversely, over-stocked (Swift et al., 2019), and improving flexibility (Wang and Wei, 2007). Studies have also analyzed the antecedents of supply chain visibility from both non-technical and technical perspectives (Barratt and Oke, 2007). Relationship commitment (Moberg et al., 2002), inter-organizational trust (Barratt and Oke, 2007), and internal and external supply chain linkages (Barratt and Barratt, 2011) are considered to be the key non-technical factors affecting supply chain visibility, whereas the deployment of big data analytics (Wamba et al., 2020) and the Internet of Things (Parry et al., 2016) are two important technical factors promoting supply chain visibility.

Supply chain agility refers to the ability of a supply chain to adjust swiftly to unexpected or rapid market changes (Wamba et al., 2020). Firms with agile supply chains can predict demand more accurately, are more sensitive to the market, and respond better to market changes (Christopher, 2000). Therefore, supply chain agility is key to reducing the risk of supply chain disruptions (Braunscheidel and Suresh, 2009) and promoting competitive advantage (Chan et al., 2017). Many studies have explored the factors that influence supply chain agility (Shekarian et al., 2020). For example, Kim and Chai (2017) survey 272 manufacturing firms and find that frequent information sharing in the supply chain helps to make quick decisions and respond to market changes. By investigating 141 apparel manufacturers, Chan et al. (2017) find that two organizational flexibility factors (i.e., strategic flexibility and manufacturing flexibility) are key prerequisites for supply chain agility. Based on a sample of 300 manufacturing firms in Thailand, Srimarut and Mekhum (2020) illustrate that big data analytics show a significant effect on supply chain agility.

Overall, although prior studies have emphasized the importance of DT asset deployment in building supply chain visibility and agility (Rai et al., 2006; Swafford et al., 2008; Liu et al., 2013; Yang, 2014; Wamba et al., 2020), most research focuses on the role of specific DTs, rather than investigating the overall impact of DT asset deployment. This gap lessens the current understanding of how various combinations of different DT assets affect business operations.

2.3. Supply chain performance

Because supply chain management may increase organizational productivity and profitability while creating value for stakeholders along the supply chain (Estampe et al., 2013), some scholars believe that a firm's success is initially determined by the performance of its supply chain (Rosenzweig et al., 2003). In particular, supply chain performance measures the ability of a firm's supply chain to provide high-quality products and services in precise quantities and at precise times to end consumers (Whitten et al., 2012). The literature has discussed the factors that affect supply chain performance. For example, Kochan et al. (2018) utilize the system dynamics approach to model a hospital supply chain and discover that increasing supply chain visibility improves customer response and reduces inventory costs. Through an investigation of 205 top managers in purchasing, production, and supply chain functional areas, Tarafdar and Qrunfleh (2017) argue that supply chain agility enables firms to better adapt to customer needs and satisfy customers in product delivery and service. Other elements that contribute to improving supply chain performance include supply chain collaboration (Vachon and Klassen, 2008), integration (Shee et al., 2018), and flexibility (Srinivasan and Swink, 2018). Overall, although the prior work has identified various factors that influence supply chain performance, the present study expands on and differs from past studies by systematically investigating relationships among DT asset deployment, supply chain visibility, supply chain agility, and supply chain performance from an asset orchestration perspective.

3. Hypothesis development

3.1. Relationship between DT asset deployment and supply chain visibility

The prior work has illustrated that access to information is an essential element of achieving supply chain visibility (Williams et al., 2013). Given that firms with broad DT asset deployment are more likely to build inter-firm partnerships (Zhang et al., 2016), such firms may acquire information from multiple sources (e.g., suppliers, customers, and markets), resulting in the improvement of supply chain visibility. For example, through the wide use of the Internet of Things, the focal firm can exchange information with all parties involved in the supply chain and facilitate the monitoring and control of its supply chain and realize end-to-end transparency (Gartner, 2020). Moreover, information authenticity is another key element for supply chain visibility (Kamble et al., 2019). Undoubtedly, widespread deployment of DT assets, particularly blockchain and radio frequency identification (RFID), among different supply chain members, can reduce the possibility of human error and fraud while also improving the quality of information obtained, thereby providing an effective information foundation for the focal firms' supply chain visualization (Rogerson and Parry, 2020). Kamble et al. (2020) also show that due to the characteristics of traceability and auditability, some members in the agriculture supply chain are more willing to jointly deploy the blockchain to visualize their supply chains.

Some scholars suggest that to achieve true supply chain visibility, firms must go beyond simply knowing what is occurring, to anticipating what will happen (Chavez et al., 2017). Such an argument indicates that information obtained by firms should guide decision-making (Bailey and Francis, 2008). More precisely, a high-visibility supply chain should not only have the adequate and correct information but also have the ability to determine the best supply chain decisions and trade-offs by leveraging analytics techniques and tools (Fatorachian and Kazemi, 2020). Given that firms with in-depth DT asset deployment may be better able to use their organizational procedures to integrate with their supply chain partners (Zhang et al., 2016), such firms may make greater use of DT assets to manage the information collected, to better inform supply chain decision-making. Gartner (2020) reports that with the assistance of big data analytics and artificial intelligence, Unilever can extract valuable information based on data from thousands of partners and millions of products, thereby obtaining real-time insights into the supply chain, identifying bottlenecks, and mitigating potential risks. Ketchen and Craighead (2020) also illustrate that compared with firms with relatively low levels of big data analytics, firms with higher levels of big data analytics can better monitor and understand the status of their suppliers during the COVID-19 pandemic, contacting alternative suppliers early to ensure the stability of raw material supply. In accordance with the above observations, we propose:

H1a. The breadth of DT asset deployment is positively associated with supply chain visibility.

H1b. The depth of DT asset deployment is positively associated with supply chain visibility.

3.2. Relationship between DT asset deployment and supply chain agility

One of the major components of agility is the accessibility of information (Kim and Chai, 2017). Apparently, having a significant amount of reliable and timely data assists firms in accurately determining supply and demand, allowing them to immediately recognize and respond to market changes (Christopher, 2000). Extensive DT asset deployment indicates more inter-enterprise relationships (Zhang et al., 2016), and such relationships enable firms to have quick access to all their upstream and downstream supply chain partners' real-time demand, inventory, and production information, rather than relying on the firm's IT department to provide reports that take time to produce (Parry et al., 2016). In fact, for real-time access to the global supply chain, some firms, such as Procter and Gamble (P&G), use a digital platform to connect all of their supply chain partners; more importantly, such a digital platform can help firms swiftly recognize market changes and build agile supply chains based on real-time order inventory, shipment, and payment data (Maqueira et al., 2019).

Two other components of agility are sensing and responding (Roh et al., 2014). Sensing reflects a firm's ability to recognize changes, opportunities, and risks swiftly (Rosenzweig and Roth, 2007), whereas responding refers to the ability to make decisions rapidly after perceiving changes (Roh et al., 2014). On the one hand, firms that deploy DT assets on a larger scale tend to make better use of DT assets to complement their organizational practices and support their decision-making (Zhang et al., 2016), and such firms may have better information-processing capabilities and thus be better able to sense changes in the market (Li et al., 2021). On the other hand, firms with in-depth DT asset deployment can better leverage DT assets to integrate their supply chain partners (Zhang et al., 2016); and such supply chain integration allows firms to coordinate their supply networks to rapidly respond to unforeseen changes in a turbulent environment (Braunscheidel and Suresh, 2009). For example, with the assistance of a deeply integrated digital system, JD.com can analyze and predict product sales changes based on downstream firms' and market data, which allows it to formulate an early response plan; more importantly, such a plan has allowed JD.com to shorten the traditional supply chain development to delivery time from twelve months to six months (Mak and Shen, 2021). Other examples of in-depth DT asset deployment being used to shorten delivery times and build a more agile supply chain include UPS's employment of 3D printing technology to create products directly in distribution centers, and Amazon's use of robots in automated packaging systems (Ivanov et al., 2019). Hence, we pose:

H2a. The breadth of DT asset deployment is positively associated with supply chain agility.

H2b. The depth of DT asset deployment is positively associated with supply chain agility.

3.3. Relationship between supply chain visibility and supply chain agility

We argue that good supply chain visibility is the foundation for achieving an agile supply chain. The reasons are that, on the one hand, supply chain agility requires firms to sense the changes in turbulent environments (Srinivasan and Swink, 2018), and, thus, firms need first to obtain certain information related to the market, suppliers, and customers (Kim and Chai, 2017). Obviously, a high degree of supply chain visibility usually means that firms can obtain relatively high-quality information, which forms the basis for firms to perceive and predict environmental changes. In the early stage of the COVID-19 outbreak, for example, an auto parts manufacturer in Europe closely monitored and evaluated the potential impact of COVID-19 on its suppliers in Wuhan, and this enabled it to swiftly alter its existing transportation route and maintain a steady supply of auto parts after the Wuhan lockdown (EverSream, 2021). On the other hand, owing to the support of real-time data analysis capabilities, supply chain visibility may help a firm adapt more rapidly to environmental changes (Park et al., 2017). For instance, P&G has established a decision support system that can access all data in real-time; when the plant requires emergency repairs, P&G can utilize the real-time data to modify product routes in time to meet customer demands (Galbraith, 2014). Based on these observations, we propose:

H3. Supply chain visibility is positively associated with supply chain agility.

3.4. Effects of supply chain visibility and agility on supply chain performance

According to the literature, two key aspects of good supply chain performance are providing on-time delivery and minimizing safety stocks (Whitten et al., 2012). In particular, providing on-time delivery requires firms to balance supply and demand to avoid shortages, and minimizing safety stocks means maintaining the lowest inventory level without incurring the risk of inventory shortages induced by supply and demand uncertainty (Whitten et al., 2012). Undoubtedly, a high degree of supply chain visibility is generally linked to high-quality supply and demand information (Barratt and Oke, 2007), which may help to decrease the bullwhip effect produced by supply and demand uncertainty (Lee et al., 1997), to eliminate supply and demand imbalances, to guarantee on-time delivery, and to reduce the level of safety stocks. For example, it was recently reported that firms' use of the FourKites real-time supply chain visualization platform increases the percentage of on-time and full deliveries by 38% and reduces lead times by 14% (CSCMP, 2021); more importantly, such shortened delivery times can greatly reduce the safety stock levels of these firms (Shee et al., 2018). Hence, we believe that supply chain visibility is positively linked to supply chain performance; that is, higher supply chain visibility leads to more just-in-time delivery and lower safety stocks levels.

However, Ivanov (2020) argues that, in a turbulent environment, to deliver items on time and minimize safety stocks, relying on supply chain visibility alone is not enough: firms must also have the ability to quickly sense and respond to the market; that is, they must build supply chain agility. This is because supply chain agility is frequently linked to information integration and coordination among supply chain participants (Liu et al., 2013). On the one hand, information integration enables firms to detect and respond to market developments in real-time, ensuring on-time product delivery, reducing demand uncertainty, and resulting in lower safety stock levels (Kim and Chai, 2017). On the other hand, firms' coordination with their supply chain partners encourages them to develop a shared vision and share resources (Liu et al., 2013); and, more importantly, such coordination gives firms more flexibility in reconfiguring their resources to make products, allowing them to cope better with market uncertainties. The above point of view is supported by some real cases. For example, by establishing an agile supply chain, Unilever has greatly shortened delivery times and reduced safety stocks, thereby improving supply chain performance (Gartner, 2020). Through the construction of an agile logistics distribution mode, JD.com has far outperformed its main competitors in terms of supply chain performance, especially timely delivery (Zheng et al., 2020). Accordingly, we propose:

H4. Supply chain visibility is positively associated with supply chain performance.

H5. Supply chain agility is positively associated with supply chain performance.

Drawing on the above arguments, we summarize the proposed framework in Fig. 1.

4. Methods

4.1. Data collection

China is one of several major developing countries devoted to increasing business digitalization. According to the "National Informatization Development Strategy Outline" issued by the State Council of China, China aims to build by 2025 an internationally leading mobile communication network and achieve substantial progress in digitalization, networking, and intelligence in key industries (XINHUANET, 2016). Moreover, although China was one of the first major countries to suffer from the COVID-19 pandemic, it has shown great resilience (Wang et al., 2020). The International Monetary Fund (IMF) reported that the global economy shrank by 3.3% in 2020, whereas China's economy achieved 2.3% growth, — the only major economy that has achieved any growth (IMF, 2021). For these two reasons and because DTs have played a critical role in helping Chinese firms to recover from the COVID-19 pandemic (Schwertner, 2017), we focus on Chinese firms. In short, the investigation of Chinese firms is not only conducive to summarizing the successful experience of Chinese firms in using DTs to deal with the COVID-19 challenge but also provides guidance for firms in

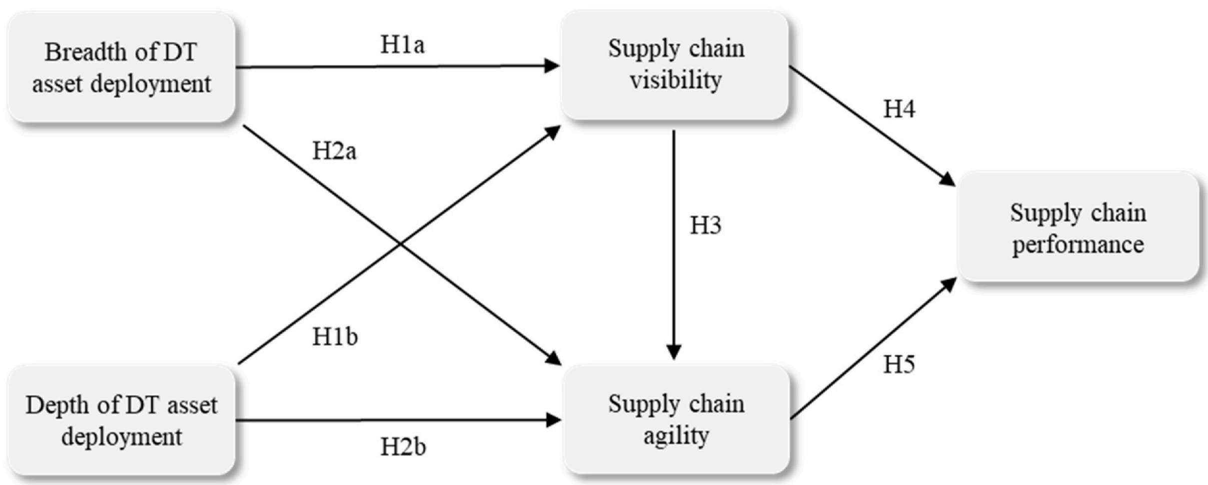

Fig. 1. Research framework.

other regions to deploy their digital strategies during the ongoing COVID-19 crisis.

We developed a survey instrument and invited 20 MBA students to participate in a pre-test. After polishing some wording and evaluating the time required to complete the questionnaire, we collaborated with a professional survey company and paid a certain commission. In particular, we first asked the survey company to provide us with a list based on their sample pool, so that we could pick some firms at random from this list to investigate. Then, the survey company helped us send the questionnaires, along with a cover letter that highlighted the potential contribution of the responding firms, to the targeted firms by email. In accordance with our research purpose, the respondents were limited to top managers or departmental managers (e.g., IT managers, business managers, and operations managers), and the firms they worked for had adopted at least one type of DT before the survey. Throughout the survey process, the survey company additionally embedded several screening questions in our questionnaire to determine whether the respondents answered the questionnaire seriously. Finally, respondents who completed the questionnaire were eligible for an instant award (i.e., e-shopping coupons) from the survey company. Of the 400 managers contacted, 175 of them provided useable responses, thus incurring a response rate of 43.75%.

Table 1 provides the characteristics of respondents. All respondents held management positions, and just over half were male (58.86%). Most were in the 36–45 age group (40.00%) and held a bachelor's degree or postgraduate degree (92.57%). Table 1 also reveals the characteristics of the respondents' firms. Most were private firms (69.71%) and were in the manufacturing industry (56.00%). Over 71% had been established for more than 10 years and over 44% had more than 500 employees.

We first examined the non-response bias and found no significant differences ($p > 0.10$) between the first and last quarters of the responses with regard to employee numbers and years in business. We then used the marker-variable technique to test common method bias. According to the work of Lindell and Whitney (2001), the size of the respondent's shoes was a good marker variable because it was theoretically irrelevant to other variables in this study. As shown in Table 2, we found that there was no significant correlation between the marker variable and other variables, thus confirming our inference. Moreover, controlling for common method bias had no impact on the statistical significance of the correlations between variables. Hence, common method bias did not pose a risk to our research.

4.2. Measures

We developed measurement items from the literature on information

Table 1
Sample characteristics.

Firm information	Frequency	Percentage	Respondent information	Frequency	Percentage
Ownership			Gender		
State-owned	27	15.43%	Male	103	58.86%
Privately owned	122	69.71%	Female	72	41.14%
Foreign	26	14.86%	Respondent age		
Firm age (years established, to 2021)			26–35 years old	69	39.43%
10 and below	50	28.57%	36–45 years old	70	40.00%
11–20 years	63	36.00%	45 and above	36	20.57%
20–30 years	44	25.14%	Educational level	69	39.43%
30 years and above	18	10.29%	Associate degree or below	13	7.43%
Firm size (number of employees)			Bachelor's degree	121	69.14%
<100	25	14.29%	Postgraduate degree	41	23.43%
100–500	71	40.57%	Respondent title		
500–1000	57	32.57%	Operations/IT manager	77	44.00%
>1000	22	12.57%	Business unit manager	66	37.71%
Industry types			Top manager	32	18.29%
Manufacturing	98	56.00%			
IT industry	47	26.86%			
Retailing	16	9.14%			
Infrastructure industry	6	3.43%			
Logistics industry	4	2.29%			
Other industrial sectors	4	2.29%			

Table 2
Correlation matrix and discriminant validity.

	1	2	3	4	5
1. Breadth of DT asset deployment	**0.749**				
2. Depth of DT asset deployment	0.674**	**0.762**			
3. Supply chain visibility	0.627**	0.643**	**0.734**		
4. Supply chain agility	0.478**	0.585**	0.580**	**0.751**	
5. Supply chain performance	0.578**	0.647**	0.652**	0.601**	**0.709**
6. Marker variable	−0.047	0.018	−0.120	−0.013	−0.095

Notes: ** represents P-value < 0.01; the numbers on the diagonal are the square root of AVEs.

systems and supply chain management. We used a seven-point Likert scale to measure all the items and summarized them in Appendix A, Fig. A1. In particular, to measure the breadth of DT asset deployment, we used three items: the proportion of partners for which DT assets were used for interaction; the proportion of partner transactions done through DT assets; and the proportion of overall interactions with partners carried out through DT assets (Zhang et al., 2016). To measure the depth of DT asset deployment, we used three items that captured the extent to which DT assets were used in purchase management, partner selection, and demand management (Zhang et al., 2016). Because supply chain visibility involved customer visibility, supplier visibility, and market visibility, we used six items adapted from Williams et al. (2013) to measure them. In addition, we adapted three items from Wamba et al. (2020) to measure supply chain agility, which reflected whether the firm strived to facilitate the flow of information up and down the supply chain, build partnerships with suppliers, and establish a crisis management team. Furthermore, four items adapted from Whitten et al. (2012) were used to measure supply chain performance, and these four items reflected the extent to which a firm's supply chain provided high-quality products and services in the COVID-19 crisis.

Finally, on the one hand, similar to the work of Liu et al. (2016), we set firm age (the number of years the firm had been established, to 2021), firm size (in terms of the number of employees), ownership, and industry types as the main control variables. On the other hand, the asset orchestration perspective first emphasized the selection of assets and then the deployment of assets (Sirmon and Hitt, 2009). Hence, we considered five common DT assets: big data analytics, cloud computing, the Internet of Things, artificial intelligence, and blockchain, which accounted for 86.86%, 62.29%, 56.57%, 40.00%, and 28.00% of the total sample, respectively, thus far higher than the proportions of other types of DT assets. If we directly adopted dummy coding to code different DT assets, then we might ignore the synergies between different types of DT assets. In contrast, if we listed all of the DT asset portfolios, this work was enormous because theoretically, a total of 31 portfolios existed for five DT assets. To this end, we adopted a compromise approach, that is, we mainly focused on seven DT asset portfolios: (1) big data analytics; (2) big data analytics + artificial intelligence; (3) big data analytics + cloud computing; (4) big data analytics + the Internet of Things + cloud computing; (5) big data analytics + artificial intelligence + the Internet of Things; (6) big data analytics + artificial intelligence + the Internet of Things + cloud computing; and (7) big data analytics + artificial intelligence + the Internet of Things + cloud computing + blockchain. The main reason was that these seven DT asset portfolios accounted for 53.71% of the total sample. Accordingly, these seven DT asset portfolios were also regarded as important control variables in this study.

5. Results

5.1. Measurement model

We first perform confirmatory factor analysis (CFA) to assess the measurement model and summarize the results in Table A1 in Appendix A (Li et al., 2020). The CFA results show that the model fits are good: $\chi^2 = 175.294$, $df = 142$, $\chi^2/\text{df} = 1.234$, Incremental Fit Index (IFI) = 0.980, Tucker-Lewis Index (TLI) = 0.975, Comparative Fit Index (CFI) = 0.979, and root mean square error of approximation (RMSEA) = 0.037. In addition, indicator reliability, composite reliability, convergent validity, and discriminant validity all meet the standards (Nunnally, 1978). In particular, Cronbach's α for each variable is above 0.7, the composite reliability (CR) and the average variance extracted (AVE) are above the critical values of 0.7 and 0.5, respectively (Bagozzi and Yi, 1998); and the square roots of AVEs are above the inter-construct correlations (see Table 2) (Fornell and Larcker, 1981). Therefore, our measurements can be used for further analysis.

5.2. Structural model

To test our hypotheses, we employ a structural equation model (SEM) run by Amos 21.0 and present the results in Fig. 2. Overall, the model fit indices are good: $\chi^2 = 492.855$, $df = 400$, $\chi^2/\text{df} = 1.232$, IFI = 0.964, TLI = 0.941, CFI = 0.960, and RMSEA = 0.037. Both the breadth ($\beta = 0.295, p < 0.05$) and the depth ($\beta = 0.434, p < 0.01$) of DT asset deployment improve supply chain visibility, thereby supporting H1a and H1b. However, when we look at the relationship between DT asset deployment and supply chain agility, we find that although the depth of DT asset deployment positively influences supply chain agility ($\beta = 0.615$, $p < 0.01$), the breadth of DT asset deployment has no discernible effect on supply chain agility ($\beta = -0.226, p > 0.10$). These findings thereby support H2b but reject H2a. Lastly, with respect to the relationships between supply chain visibility, supply chain agility, and supply chain performance, we find that the higher the supply chain visibility is, the greater is the supply chain agility ($\beta = 0.347, p < 0.05$) and the better is supply chain performance ($\beta = 0.524$ $p < 0.001$), thus supporting H3 and H4. We also find a positive relationship between supply chain agility and supply chain performance ($\beta = 0.367$, $p < 0.001$), thereby supporting H5. Finally, regarding control variables, we find that firm age, firm size, ownership, and industry types do not show significant relationships with firm performance. Interestingly, when DT asset portfolios chosen by the company are big data analytics ($\beta = 0.371, p < 0.10$), big data analytics + cloud computing ($\beta = 0.179$, $p < 0.10$), and big data analytics + the Internet of Things + cloud computing ($\beta = 0.204$, $p < 0.10$), such firms typically show better supply chain performance.

6. Discussion

Whereas Zhang et al. (2016) focus on the breadth and depth of the deployment of inter-organizational systems (IOSs), we extend the research object from IOSs to DT assets. Although Zhang et al. (2016) find that the breadth and depth of IOS deployment always lead to operational improvement, we find that the breadth and depth of DT asset deployment have different impacts on supply chain visibility and supply chain agility. First, we find that both the breadth and depth of DT asset deployment improve the visibility of the supply chain. This finding is supported by previous evidence to some extent. For example, Rogerson and Parry (2020) illustrate how the deployment of technologies such as blockchain, RFID, and Industry 4.0 among supply chain members improves the timeliness and accuracy of the information and achieves end-to-end transparency. Li et al. (2021) reveal that with the assistance of DT assets, such as big data analytics and artificial intelligence, firms can extract important information from a vast volume of scattered data

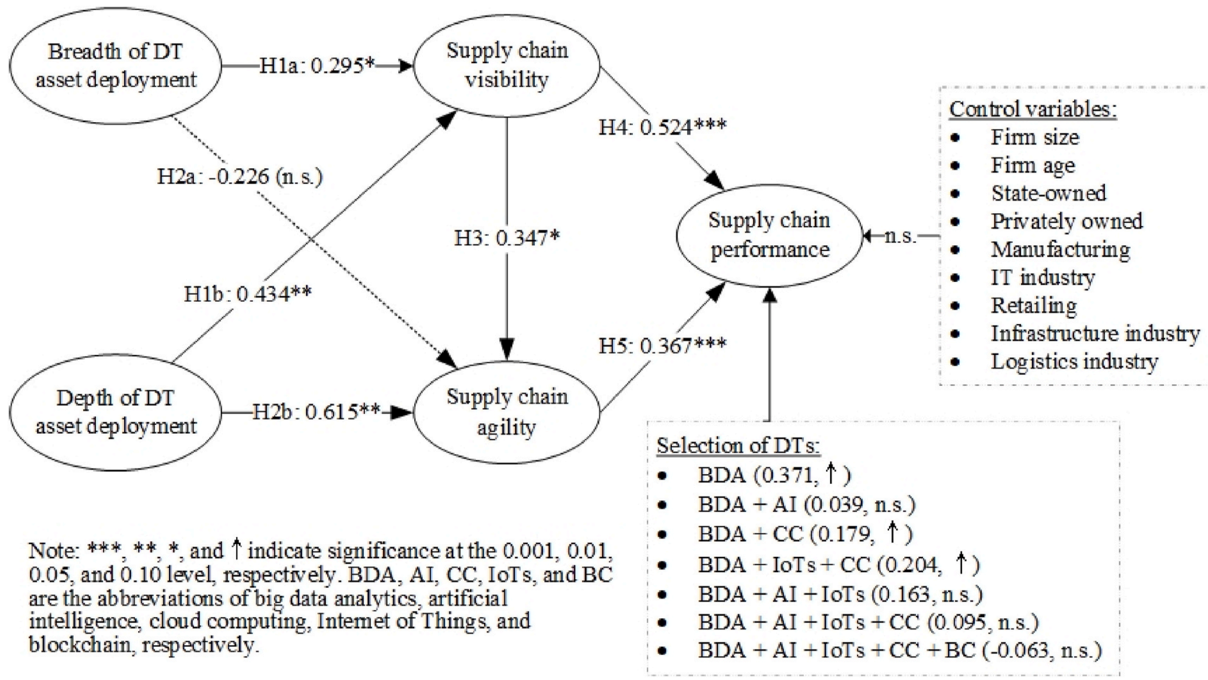

Fig. 2. Results of the structural model.

to aid decision-making, thereby achieving real supply chain visibility, that is, going beyond simply knowing what is occurring to anticipating what will happen.

Second, regarding the relationship between DT asset deployment and supply chain agility, we are surprised to discover that only the depth of DT asset deployment improves supply chain agility, whereas the breadth of DT asset deployment has no significant influence, unlike prior findings (Wamba et al., 2020). One possible explanation for this is that although the breadth of DT asset deployment can bring more inter-organization connections and a more transparent supply chain, more data is not always better data (Corbett, 2018). Managers may be overwhelmed by the large amount of data produced by a highly transparent supply chain (Surbakti et al., 2020). More importantly, this "digital redundancy" may interfere with managers' decision-making, especially in the face of crises (Li et al., 2021). Some previous findings support this argument to a certain extent. For example, Bailey and Francis (2008) find that there are significant demand distortions in a highly transparent supply chain. Srinivasan and Swink (2018) suggest that supply chain agility is determined not only by an organization's ability to receive information but also by its ability to process and apply that information; this implies that a mismatch between the amount of information obtained and information processing capability can reduce supply chain agility. In fact, with respect to the distinct effects of the depth and breadth of technology utilization on business operations, prior work has reported findings similar to ours. In particular, Li (2019) reveals that in the digital environment, the depth of external information search promotes demand-driven and technology-driven business models, whereas the breadth of external information search inhibits the adoption of such models.

Previous studies separately examine the relationship between supply chain visibility and supply chain performance, and the relationship between supply chain agility and supply chain performance (Williams et al., 2013; Chan et al., 2017; Dubey et al., 2018; Swift et al., 2019). We examine these relationships conjointly and find that supply chain visibility, supply chain agility, and supply chain performance are positively linked with each other. These mutual connections are supported by both research findings and real-life examples. Dubey et al. (2018) and Srinivasan and Swink (2018) believe that a high level of supply chain visibility provides support for firms' decision-making, thus constituting a foundation for improving supply chain agility and supply chain performance. Moreover, Tarafdar and Qrunfleh (2017) argue that an agile supply chain enables firms to provide customers with better-quality products and services faster, and to reduce their levels of safety stocks, resulting in superior supply chain performance. McKinsey (2018) reports that some firms worldwide have merged data from procurement, part tracking, and inventory monitoring into a single platform to achieve real-time visibility across the entire supply chain. More importantly, such real-time visibility has increased procurement productivity by 20% and on-time delivery rates by 5%, reflecting greatly improved supply chain performance.

6.1. Theoretical implications

We contribute to the digital supply chain management literature in the following three respects. First, while past studies have explored the impact of DT asset deployment on supply chain management, they are mainly concerned with the role of specific DTs, such as big data analytics (Wamba et al., 2020), blockchain technology (Musigmann et al., 2020), cloud computing (Maqueira et al., 2019), and the Internet of Things (Ivanov et al., 2019). However, firms rarely use a single DT asset in their day-to-day supply chain management, but rather a combination of several DT assets (Maric et al., 2021). This is because different DT assets have their own shortcomings, and the combined use of multiple DT assets can maximize the value of each DT asset while overcoming the shortcomings of a single DT asset (Ivanov et al., 2019). Hence, focusing solely on the role of a particular DT asset may impose constraints on the firm's overall operations and the development of digital strategies. By contrast, investigating the impact of two aspects (scale and scope) of a range of DT asset deployment on supply chain management from a holistic perspective can not only indirectly validate previous findings on the role of specific DTs but also help scholars further examine the effectiveness of different digital strategies.

Second, we provide a new understanding of digital supply chain management from an asset orchestration perspective (Zhang et al., 2016). The majority of the literature examines the impact of DT asset deployment on firm performance with reference to the resource-based view (Ardolino et al., 2017) or dynamic capacity theory (Wamba et al., 2020). However, in the context of DT asset deployment, some basic assumptions of the resource-based view, especially the scarcity of resources, may not be satisfied (Braganza et al., 2017). In addition, dynamic capability theory may not disclose the relevance of a firm's asset selection and deployment (Sirmon et al., 2011), leading to an oversimplified understanding of the drivers and outcomes of firms choosing different DT assets. Unlike the above two theoretical perspectives, the asset orchestration perspective stresses that the synergy of multiple assets, rather than the independent influence of a single asset, affects the deployment outcomes (Zaefarian et al., 2013). This implies that the efficient use and management of different assets is more essential than the assets themselves for the operation of a firm (Chirico et al., 2011). In short, investigating from an asset orchestration perspective can overcome the limitations of some other research perspectives, thereby allowing scholars to re-examine the impacts of DT asset deployment on supply chain management.

Third, although previous studies have investigated the relationships among supply chain visibility, supply chain agility, and supply chain performance (Whitten et al., 2012; Kochan et al., 2018; Ivanov, 2020), most of the findings are obtained in the context of a relatively stable market (Srinivasan and Swink, 2018). However, the COVID-19 pandemic has caused significant market volatility on a global scale (Tietze et al., 2020), which may mean that previous findings will no longer generally apply. Ojha et al. (2014) suggest that it is risky to utilize findings from diverse market contexts to guide practice when the external environment changes. Accordingly, investigating the relationships among supply chain visibility, supply chain agility, and supply chain performance in a turbulent environment can enhance the robustness of research findings (Sarkis, 2020). Moreover, in contrast to previous studies that show DT asset deployment to be always positively linked with supply chain agility (Wamba et al., 2020), our findings suggest that different aspects of DT asset deployment have distinct impacts on supply chain agility. In particular, the depth of DT asset deployment is positively linked to supply chain agility, but not the breadth of DT asset deployment. This finding can help scholars to re-examine DT-enabled supply chain management activities (Zhang et al., 2016).

6.2. Managerial implications

Our findings also provide some implications for firms' digital supply chain management. First, the COVID-19 outbreak has brought global firms' attention to supply chain management to the highest level in history. This is because digitalization is an important way to improve the efficiency of supply chain operations. According to our study, we suggest that when facing the challenge of the COVID-19 pandemic, firms' DT asset deployment strategy should focus on the combination of big data analytics, the Internet of Things, and cloud computing. However, for most firms, especially small and medium-sized enterprises (SMEs), deploying DT assets is still a difficult problem. On the one hand, the cost of DT asset deployment is prohibitive for some SMEs. Moreover, most firms are still in the early stages of DT asset deployment, with low levels of production data, a lack of deep business and data integration, and a gap between system digitization and implementation. Hence, to assist such firms to deploy their DT assets, governments should provide more policy support and ensure the smooth flow of funding. Moreover, digital service providers should offer more professional products and services tailored to the development demands of various industries, allowing firms to select the best third-party cloud platform services for their specific requirements, for example.

Second, the DT asset deployment of firms should be mutually complementary and compatible. In particular, firms should extend their DT asset deployment to gain more inter-firm linkages, as well as deepen their DT asset deployment to improve supply chain integration. To this end, firms can deploy DT assets, like cloud computing and blockchain, to broaden the scope of DT asset deployment, promote real-time information sharing and access among firms, break down data silos, and connect data across departments and firms, allowing them to better utilize data resources and capitalize on the value of data. In addition, firms should expand the depth of their DT asset deployment by deploying other DT assets, such as big data analytics and artificial intelligence, allowing them to perform real-time data flow analysis and extract value from large amounts of data; all this will ultimately result in competitive advantages. In short, firms should thoroughly grasp the circumstances and functions of DT asset deployment before rationally matching DT assets to their own requirements and capacities. After the deployment is complete, firms should update their DT asset portfolio to reflect changes in the market, technical advancements, and their own capabilities.

7. Conclusion

To understand whether firms that have higher levels of DT asset deployment can achieve superior supply chain performance in the COVID-19 crisis, we survey 175 Chinese firms that have deployed DT assets to varying degrees. Based on the asset orchestration perspective, we divide the deployment of DT assets into two dimensions: breadth, which reflects the scope of DT asset deployment; and depth, which captures the scale of DT asset deployment. Our results reveal that both the breadth and depth of DT asset deployment show positive associations with supply chain visibility. In contrast, the depth but not breadth of DT asset deployment displays a positive linkage with supply chain agility. Last but not least, supply chain visibility and supply chain agility are two key factors that have helped firms achieve excellent supply chain performance in the COVID-19 crisis. Overall, we contribute to the current digital supply chain management literature by revealing the mechanism of how different types of DT asset deployment strategies affect supply chain performance. We hope that our findings can help firms improve their digital strategies to survive the COVID-19 pandemic.

Like any other research, two aspects of this research could be strengthened. First, we mainly investigate the relationships between the breadth and depth of DT asset deployment and supply chain performance from the perspective of the configuration/deployment dimension of asset orchestration. Although we try our best to control the influence of the search/selection dimension of asset orchestration and the synergy effect between different DT assets by incorporating the combinations of DT assets that have been adopted by responding firms into our model as control variables, our research can only provide limited explanations in illustrating the fit between a firm's asset selection and deployment. Therefore, future studies can employ more efforts to refine this limitation. Second, in this paper, we primarily focus on DT assets that are controlled and owned by the focal firms, and thus, DT assets are regarded as internal resources. However. A firm's resources include not only those within the organization but also between its supply chain partners, that is, external resources. Therefore, future work can expand our study from a broader theoretical perspective, especially the resource orchestration perspective that integrates both the asset orchestration and resource management frameworks.

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Appendix A

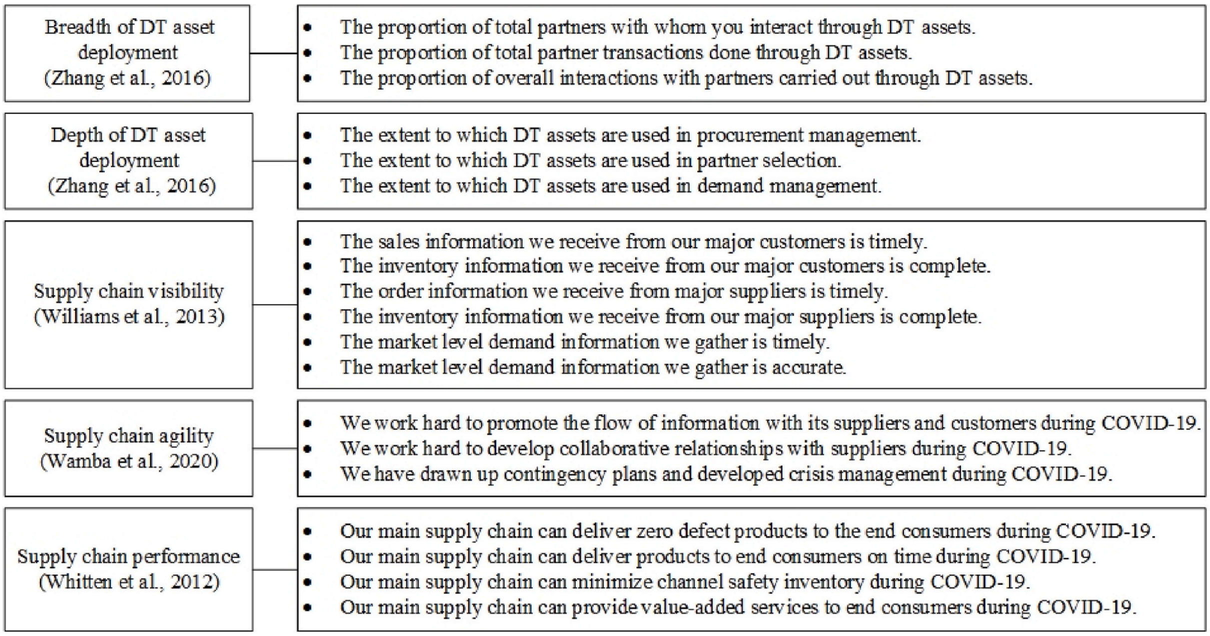

Fig. A1. Measurement items

Table AI
Measurement assessment results of CFA

Items	Mean	Standard deviation	Factor loadings	CR	AVE	Cronbach's α
BRE1	5.451	0.926	0.820	0.792	0.561	0.792
BRE2	5.457	0.908	0.694			
BRE3	5.469	0.927	0.727			
DEP1	5.497	0.915	0.790	0.806	0.580	0.806
DEP2	5.657	0.957	0.732			
DEP3	5.583	0.978	0.762			
SCV1	5.714	0.829	0.775	0.875	0.539	0.873
SCV2	5.600	0.983	0.714			
SCV3	5.720	0.828	0.763			
SCV4	5.640	0.865	0.702			
SCV5	5.754	0.818	0.757			
SCV6	5.646	0.864	0.688			
SCA1	5.811	0.812	0.769	0.795	0.564	0.793
SCA2	5.880	0.839	0.744			
SCA3	5.777	0.911	0.739			
SCP1	5.646	0.903	0.725	0.801	0.503	0.801
SCP2	5.617	0.869	0.670			
SCP3	5.543	0.862	0.704			
SCP4	5.474	0.958	0.735			

Notes: BRE, DEP, SCV, SCA, and SCP are the abbreviations of the breadth of DT asset deployment, the depth of DT asset deployment, supply chain visibility, supply chain agility, and supply chain performance respectively.

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