Mitigating the Bullwhip Effect through Supply Chain ESG Transparency: Roles of Digitalization and Signal Strength

Abstract

Purpose – The call for supply chain transparency (SCT), especially the Environmental, social, and governance (ESG) aspect, is getting increasingly louder. Based on the signaling theory, our study investigates the operational benefit of supply chain transparency in terms of ESG (SCT-ESG). To further clarify the signaling process, the moderating role of digitalization of the firm and signal strength are also examined.

Design/methodology/approach – Longitudinal secondary data from multiple databases are matched and analyzed using ordinary least squares (OLS) regressions to validate the proposed hypotheses.

Findings – Results suggest that with SCT-ESG, firms have a weakened disparity between production variance and demand variance, and the supply chain experiences a reduced bullwhip effect. Further, digitalization of the focal company and signal strength reinforce the negative effect of SCT-ESG on the bullwhip effect.

Originality – The study integrates the SCT and ESG literature through SCT-ESG, extending benefits of ESG disclosure to the supply chain context. It extends the application of the signaling theory in OSCM by including contextual factors of digitalization and signal strength.

Keywords: supply chain transparency; ESG transparency; bullwhip effect; digitalization; signal strength; noise

Research paper

1. Introduction

The call for supply chain transparency (SCT), understood as supply chain members' disclosure of information, is getting increasingly louder among stakeholders. Buyers require information regarding the origin of the materials they source, and external stakeholders such as non-governmental organizations (NGOs) are pressing the supply chain to share more information on their environmental impact. SCT depends on the amount and quality of information sharing within the supply chain and to external stakeholders (Mollenkopf *et al*., 2022), which is beyond any individual company's capacity and requires collective and coordinated efforts by all involved (Gualandris *et al*., 2021). So far, mandatory information disclosure is still limited to certain business and geographical areas, and voluntary disclosure by companies remains the main channel for SCT.

It is agreed that SCT is achieved through information sharing, and our study focuses on one of the rapidly growing fields of SCT, the Environmental, Social and Governance (ESG) transparency. ESG as a comprehensive framework is increasingly accepted as a reporting guide by business organizations. It includes environmental issues such as climate change and carbon emissions, corporate social responsibility (CSR) aspects and internal governance, which is an important non-financial performance indicator of the firm. Till 2021, over 90% of large global companies disclose information related to ESG, and the number is expected to continue to grow (Ho, 2023). As a signal that communicates a firm's practices and commitments in the three aspects to external stakeholders, it is believed that ESG transparency also has operational and supply chain implications (Lagasio and Cucari, 2019). However, there is limited empirical evidence on this.

An important indicator of supply chain efficiency is the bullwhip effect, which refers to the propagation of demand variability upstream the supply chain (Zhao *et al*., 2019). The bullwhip effect is proven widely present across industries and geographical areas (e.g., Yao and Zhu, 2012; Shan *et al*., 2014; Zhao *et al*., 2019), and information sharing, especially the sharing of demand information, is considered the key to its mitigation (Lee *et al*., 1997). However, there are challenges to communicate the demand information accurately upstream the supply chain. First, the supply chain is subject to risks which can change the demand pattern unexpectedly, and sustainability-, ethics- and governance-related factors are increasingly becoming a major source of risks. For instance, a supplier's falsification of testing results caused NASA two failed launching programs and a damage of $700 million (Zhang *et al*., 2022). Apple was under pressure to reveal more supply chain information due to negative publicity on overseas

suppliers' misbehavior regarding environmental protection (Sodhi and Tang, 2019). Monitoring and processing supply chain members' ESG behavior regularly can help predict such incidents (Lam, 2018), and the company can therefore plan production activities to minimize overactions in situations of change. Second, in traditional supply chain settings, interorganizational communications mainly happen between adjacent echelons, which can cause distortions of information along the chain (Yao and Zhu, 2012). Therefore, there is a need to develop closer relationships with supply chain members beyond the immediate echelon (Zhao *et al*., 2019; Yang *et al.*, 2020). Supply chain ESG transparency (SCT-ESG) provides a platform for wider information exchange and trust-based relationship development, which is conducive to the exchange of other information such as demand and order. Therefore, deeper interpretation of the message ESG disclosure conveys can potentially bring operational benefits such as reduced bullwhip effect and improved operational efficiency.

Our study takes a signaling perspective to investigate the potential effect of SCT-ESG on the bullwhip effect. The signaling theory informs decision-making against information asymmetry through the sending and processing of signals (Connelly *et al*., 2011). Signals are sent as an attempt to communicate unobserved attributes of the sender to external parties, aiming to reduce the information asymmetry and affect external parties' behaviors. As signals are costly to send (Lam, 2018), they can distinguish between low- and high-quality organizations and attract more favorable attitudes and actions toward high-quality organizations. The reduced bullwhip effect is, to a large extent, the result of less volatile operations and effective communications of operational data (Lee *et al*., 1997), which requires supply chain partners of trustworthiness and integrity. As a costly signal, ESG disclosure conveys the message of the organization being sustainable and responsible, reducing supply chain risks and making supply chain coordination easier. In an ESG transparent supply chain, companies tend to have trust in partners and are not likely to overreact and overstock when changes happen. Based on the core tenet of the signaling theory, the first research question our study aims to pursue is:

- *Is SCT-ESG an effective signal that can be used for organizations' decision-making to reduce the bullwhip effect?*

To fully unpack how the signal sent via ESG disclosure can reduce the bullwhip effect, we also consider boundary factors that could affect the signaling process. While it seems easy and straightforward to process a single signal, the signaling theory is less developed in contexts of complexity (Steigenberger and Wilhelm, 2018), such as a transparent supply chain full of various signals and non-signals. The signaling environment, how clear the signaler creates and

sends the signal, and the ability of the recipient to grasp key information from abundant information all affect the signaling outcome significantly (Yao *et al*., 2018). Therefore, the first boundary factor we consider is the digitalization level of the organization, which refers to the use of advanced digital technologies to optimize exiting business processes or enable new value creation models (Verhoef *et al*., 2021). Against the background of Industry 4.0, companies are gaining increasing access to digital solutions, which are proven powerful to generate, process and share real time data. Digital technologies are particularly important in contexts such as ESG reporting due to its voluntary nature and a lack of reporting standards (Tamimi and Sebastianelli, 2017). It is easier for digitalized companies to communicate and share information in a timely manner, providing room for joint planning of production (Yao and Zhu, 2012). Our second research question is:

- *Will digitalization of the firm moderate the negative association between SCT-ESG and the bullwhip effect?*

It is acknowledged that the signaling environment is an important cause of information distortion (Yao *et al*., 2018). Noise in the environment can reduce signal observability and strength, which makes it difficult for signal recipients to grasp useful information (Connelly *et al*., 2011; Bafera and Kleinert, 2023). A transparent supply chain is an environment full of various information shared by multiple agents, some of which is considered noise that blurs and distorts the focus or intent of the signal (Bafera and Kleinert, 2023). It can limit the accuracy of signal interpretation by recipients or cause them to ignore less clear signals, hence affecting the signaling outcome (Park and Patel, 2015). The intended signaling outcome is best achieved in contexts where the signal is clear and stronger relative to noise. Due to the current lack of universally accepted reporting standards for ESG, it is a challenging task to abstract useful insights from the abundant unstructured reports. When a company discloses ESG information as a signal to outsiders, it has to make sure that the signal is strong enough for the recepient to notice and process. Therefore, we also aim to shed light on the third research question:

- *Will signal strength relative to noise in the signaling environment moderate the negative association between SCT-ESG and the bullwhip effect?*

To answer these questions, we develop hypotheses based on the core tenet of the signaling theory and validate them through ordinary least squares (OLS) regressions using longitudinal archival data from the Wind and CSMAR databases. Our study intends to contribute to existing

Operations and Supply Chain Management (OSCM) literature in three ways. First, focusing on SCT-ESG, we hope to enrich existing literature by providing empirical evidence on the reduced bullwhip effect as an operational benefit of SCT-ESG. Second, engaging in the ongoing debate on "Whether ESG is just a fad for organizational image?" (Pérez *et al*., 2022), we aim to provide evidence on the tangible outcomes of ESG reporting. Our study integrates the SCT and ESG bodies of literature, which are currently separated despite high conceptual relevance. Third, we aspire to contribute to the application of the signaling theory in OSCM, highlighting the role of the signaling environment and signal characteristics in affecting the signaling process and outcomes. Positioned in the ESG context where a unified reporting standard is lacking, our study potentially advances the theoretical understanding of how desired signaling outcome can be achieved in highly complex signaling environments.

2. Literature review

2.1 Supply chain transparency (SCT)

SCT refers to supply chain members' disclosure of information to external stakeholders and the public (Gligor *et al*., 2021). The information that can be disclosed for SCT includes data on supply chain costs, products, customer duties, orders, forecasts, plans, CSR and ESG information, among others (Sodhi and Tang, 2019). Demand for higher SCT is driven by mounting pressures from various stakeholders, including the government, consumers, and activists. Companies choose to disclose more information to external parties due to legal requirements or internal motivations (Gligor *et al*., 2021). SCT enables internal and external parties to access the supply chain information, which opens the door for stricter judgment and scrutiny (Mollenkopf *et al*., 2022).

SCT represents an emerging body of research in OSCM literature. While it is generally regarded as desirable (e.g., Fosso Wamba *et al*., 2020; Mollenkopf *et al*., 2022; Dahlmann *et al*., 2023; Cui *et al*., 2023), there lacks a consensus on its conceptualization and operationalization (Mollenkopf *et al*., 2022). For instance, Bateman and Bonanni (2019) believe that a company with SCT should know what is happening in its upstream supply chain so that it can communicate the information both internally and externally. Similarly in a supply chain, relationship transparency refers to companies being informed of their main supply chain partners' actions (Zhang *et al*., 2022). These are vague claims that do not inform clearly the specific information that is needed for SCT. More specifically, Bai and Sarkis (2020), Gligor *et al*. (2021), and Montecchi *et al*. (2021) point out that SCT requires operations and product

information to be readily accessible by all supply chain members. Cui *et al*. (2023) equate SCT to the sharing of information and operationalize it as vertical cost transparency and horizontal order transparency. Chod *et al*. (2020) regard SCT as the sharing of inventory transactions and loan requests. When investigating the association between supply chain structure and transparency, Gualandris *et al.* (2021) focus on SCT in terms of ESG practices and use collective ESG disclosure by a focal firm's supply chain members as a measure. As Schäfer (2023) reveal, researchers have taken varied approaches to understanding SCT in prior empirical works, and operationalized SCT as the disclosure of information related to material, process, traceability, transaction, commitment, impact, activity and effectiveness. To sum up, scholarly discussions on "transparency of what?" is still ongoing and a wider scope of information disclosure is being advanced (Schäfer, 2023). This study focuses on the non-financial aspect of SCT, SCT-ESG.

2.2 Bullwhip effect

The bullwhip effect describes a common phenomenon of supply chain operations that the variability of demand from the downstream tends to be amplified upstream (Lee *et al*., 1997). The negative effect of bullwhip effect has been well-documented in existing literature, ranging from excessive cost of inventory to loss of innovation opportunities and revenues. It is therefore considered as a major reason for supply chain inefficiency (Yao and Zhu, 2012). According to empirical evidence, the bullwhip effect widely exists in various industries and contexts, which remains a top agenda for supply chain managers and researchers (Shan *et al*., 2014; Zhao *et al*., 2019).

Literature suggests four main causes of the bullwhip effect, including demand signaling, order batching, the rationing game, and price fluctuations (Lee *et al*., 1997). In a supply chain environment where information sharing is weak, local order information can only be shared between adjacent echelons. Companies can only carry out forecasting based on the order history of their direct customers, which does not necessarily reflect the real demand. In addition, the order information tends to get distorted moving upstream and deviate further from the real demand. Due to incentives in transportation costs and other considerations, organizations tend to order in bigger batches, which is not helpful to the transfer of real demand information along the supply chain. It worsens the situation when demand exceeds production capacity, and the firm has to play the rationing game to allocate available capacity to different buyers. Buyers will then increase their order to avoid possible stockout. Promotions and discounts at the

downstream supply chain will also affect demand, and the variation can be propagated by upstream echelons.

Having agreed on the causes of bullwhip effect, researchers are actively developing remedies. For instance, Yao and Zhu (2012) find empirical evidence that the use of IT-based electronic linkages for interorganizational information sharing can effectively reduce the bullwhip effect. Hofmann (2017) proposes the value of big data in alleviating the bullwhip effect. Zhao *et al*. (2019) confirm the role of relational capital in mitigating the bullwhip effect. Overall, a consensus has been achieved that the effective sharing of demand information among all supply chain partners is the key to mitigating the bullwhip effect (Gavirneni, 2006; Pastore *et al*., 2019). A transparent supply chain where all members willingly disclose information is an ideal context where the bullwhip effect is minimized. In addition to the lack of communication channels in the supply chain, especially between more distant echelons, companies often find it difficult to accurately grasp the demand in the first place. Supply chain risks and disruptions come from various sources that can cause considerable changes to demand. Unethical behaviors of suppliers could damage the focal company's image and consequently affect demand and cause inefficiencies in the supply chain. Our study thus investigates how signals conveyed through SCT-ESG can affect supply chain operational efficiency, focusing on the bullwhip effect.

3. Theoretical background

Signaling theory deals with the information asymmetry between parties, be them individuals or organizations (Connelly *et al*., 2011), which is of high relevance to SCT. Reducing information asymmetry is crucial in business contexts as accurate information is the basis for effective decision-making (Taj, 2016). Signaling theory has three basic elements, the sender, the signal, and the recipient. The sender/signaler, as the insider with the best knowledge about its own unobservable attributes, can decide whether or not to communicate the information, i.e., to send the signal. In our study, senders are the supply chain members who voluntarily disclose their ESG-related information to external parties. The sender often wishes to send out positive signals such as disclosing their ESG information, hoping to cause favorable perceptions and actions by outsiders. The signal then ends up with the recipient, adding to or changing its existing knowledge about the sender. In this study, recipients are companies who can observe the supply chain ESG information and use it as a reference for their own decision-making. Effective signaling processes can therefore bridge the information gap between the

sender and the recipient, facilitating collaboration and the achievement of common goals (Steigenberger and Wilhelm, 2018).

Central to the signaling theory is the creation of a "separating equilibrium" by a signal, which is confirmed through a comparison between expectations and subsequent experience (Bergh *et al*., 2014). According to Bergh *et al*. (2014), an effective "separating equilibrium" should have four essential elements. First, an information problem must be present, which is a situation with incomplete information distribution and a need for decision-making. Therefore, the signal is used by the sender to convey its unobservable characteristics and by the recipient to predict the sender's quality. For instance, an investor can use non-financial information such as ESG to predict the integrity and consequently the prosperity of a company, and make investment decisions accordingly (Chen and Xie, 2022). In our context, the signal recipient faces the question on whether or "to what extent" they should overstock to mitigate possible stockout caused by suppliers' misbehavior. Second, the signal cost distinguishes senders with high-quality attributes from those with low-quality attributes as the former are more likely to be able to absorb the cost (Steigenberger and Wilhelm, 2018). Sustainable organizations can afford to send out various (positive) signals through voluntarily disclosing sustainability-related information to distinguish them from those that are less committed. This is a costly signal to send and is verifiable, and organizations which are not sustainable tend not to mimic, making the signal credible (Lam, 2018; Song *et al*., 2023). Third, according to Bergh *et al*. (2014), the decision made by the signal recipient is optimal if the outcome meets the expectations of both parties and there are no better solutions. Last, the signal recipient forms an expectation of the signal based on its intepretation and seeks confirmation of it through experience subsequent to its decision-making. In the context of ESG disclosure, the optimizing solution occurs when a company chooses a supplier based on its ESG commitment, and later confirms that the disclosed information is true and serves as an effective basis for the transactions and cooperation between them.

Signaling theory has been widely applied in studies on voluntary sustainability disclosure. Lam (2018) finds that firm sustainable supply chain practices report as a signal reduces financial risks. More interestingly, such benefit is stronger when the signaling environment is more complex. Song *et al*. (2023) propose customer base environmental disclosure as a signal that can promote supplier greenhouse gas emissions and find empirical support for it. Friske *et al*. (2023) focus on time as a crucial element in the signaling environment and confirm its effect on the realization of value from voluntary sustainability reporting. While sustainability

reporting is found to negatively affect firm value (Tobin's q), it becomes positive over time. From a signal recipient perspective, Baumgartner *et al*. (2022) find how stakeholders' change their behavior in reactions to signals conveyed in corporate reputation disclosures.

The signaling theory provides a suitable theoretical foundation for exploring the relationship between SCT-ESG and the bullwhip effect. According to Bergh *et al*. (2014), not all information disclosure qualifies as the signaling theory's signals. The theory can only be applied when the main argument is developed based on the separating equilibrium concept. Our study explores the information challenge, the costly signal of ESG disclosure, and the comparison between signal expectations and rewards. However, despite the popularity of the theory in ESG reporting, prior studies tend to assume a simple signaling process, where the signal can go to the intended recipient and be processed effectively. In reality, environments are usually complex and full of noises (e.g., a transparent supply chain), where the signal observability and the signaling outcomes cannot be taken for granted (Connelly *et al*., 2011). As the effectiveness of the signaling process depends upon the observability of the signal, i.e., the signal's strength without distortion and deception (Connelly *et al*., 2011), any distorting factors in the signaling environment should not be overlooked. Therefore, our study examines the signaling process of ESG disclosure, and at the same time considers contextual factors that could affect the effectiveness of the process.

4. Hypotheses

4.1 SCT-ESG and the bullwhip effect

While finance and accounting researchers acknowledge that better ESG performance creates shareholder value through improving operating efficiency (e.g., Serafeim and Yoon, 2023), there is a lack of empirical evidence from OSCM. Our study proposes that this can be achieved through two main mechanisms, relationships and risk management.

First, with SCT-ESG, the search and coordination cost is largely reduced, which is conducive to more efficient relationship establishment (Yao and Zhu, 2012). ESG disclosure signals firms' practices and commitments in sustainability as well as fair governance and operations, which leads to legitimacy (Bitektine and Song, 2023), good reputation (Zerbini, 2017), and attracts those who share the same value (Liu *et al*., 2021). It is considered a strong signal that can distinguish the sender from those with lower commitment to sustainability and can affect the recipient's behavior (Song *et al*., 2023). Relationships based on similar CSR/ESG orientations represent strong relational capitals and trust, making information sharing in other regards, such

as orders and transactions, easier and more efficient (Zhao *et al*., 2019; Liu *et al*., 2021). Further, SCT-ESG alters the traditional structure where communications are restricted to immediately adjacent echelons, minimizing information distortion caused by too much interpretation and misunderstanding. Therefore, the actual demand information can be transmitted from the end of the supply chain to any echelon directly, without being seriously twisted. The bullwhip effect is thus expected reduce with SCT-ESG.

However, the actual demand is not always predictable, and SCT-ESG can support the management of risks that can potentially cause changes to demand. Systematic and unsystematic risks can cause disruptions to the supply chain and affect the demand predictably and unpredictably (Jo and Na, 2012). Strategic SCR researchers have long established the role of CSR in mitigating risks. For instance, Kim *et al*. (2021) empirically establish the reputational insurance role of CSR in fast-growing companies. Jo and Na (2012) find a negative effect of CSR engagement on firm risk in both controversial (e.g., tobacco, alcohol, gambling) and noncontroversial industries, and the effect is stronger in controversial industries. Extended to the supply chain context, the sharing of sustainable supply chain management practices conveys the message that irresponsible events are less likely to happen in the company's supply chain and will have less impact if they do happen (Lam, 2018). Using ESG information disclosed by supply chain members can help organizations assess the occurrence probability of ESG-related risks and develop mitigation strategies in advance. This prevents overreactions in situations of demand change due to insufficient understanding of the cause and consequence of an incident. Accordingly, we propose that:

H1: SCT-ESG is negatively associated with the bullwhip effect.

4.2 Digitalization

According to Sodhi and Tang (2019), real time information sharing in the supply chain is the key to solving the classic supply-demand mismatch challenge in OSCM. From a signaling perspective, a SCT-ESG environment is full of different senders and various signals, and it is a challenge for the recipient to effectively process and comprehend the abundant information (Steigenberger and Wilhelm, 2018). Digitalization refers to the deployment of advanced digital technologies to optimize exiting business processes or enable new value creation models to increase efficiency (Verhoef *et al*., 2021). In empirical studies, it is often operationalized as the use of digital technologies by the organization (Yu *et al*., 2023). Digitalized organizations are

found to be more effective in processing complex information and perform better in turbulent times (Li *et al*., 2023).

First, digitalization starts with datafication, the transformation of social activity into meaningful data that can be analyzed for business insights, providing high data availability (Leonardi and Treem, 2020). Technologies such as IoT and big data can serve this purpose by creating and recording data through applying censors or tags on each item, turning their movement, handling, and any other activities into useful data. Due to the lack of unified reporting standards for ESG, effective datafication enabled by digital technologies is needed to make the abundant unstructured information ready for subsequent sensemaking.

Second, when structured data is made available, the next step is to make sense of it for guiding organizational decision-making, where technologies such as AI come into play. AI is the machine's capability to imitate the behavior of humans through repeated communication, and the generated powerful algorithms can deal with massive amounts of data in a short period of time (Cui *et al*., 2022). The valuable insights produced by AI on supply chain ESG can help companies predict any risks that might emerge due to supplier irresponsible practices and develop precautions in advance (Lam, 2018).

Third, raw data, as well as the generated insights, need to be stored and shared securely within the organization and across the supply chain. Typically, digital technologies like blockchain or the cloud are known for enabling such activities. Blockchain, a consensus-based immutable ledger of transactions, can improve the efficiency and transparency of transactions and supply chain traceability (Jia *et al*. 2023). The cloud can store a bundle of resources in a virtualized environment which can be accessed by authorized parties on demand through web-based technologies (Maqueira *et al*., 2019). These technologies provide an information sharing platform for SCT, enabling coordination among supply chain members and reducing information asymmetry. Such a context is conducive to reduced bullwhip effect. Therefore, we propose that:

H2: The negative association between SCT-ESG and the bullwhip effect is stronger when the focal firm has a higher digitalization level.

4.3 Signal strength

Signaling theory acknowledges the existence of noise in the signaling environment, which can be caused by the environment, external referents and other signalers (Connelly *et al*., 2010). A

high-noise environment is one where multiple signals are sent at the same time (Steigenberger and Wilhelm, 2018). When supply chain members are actively disclosing various information, it is practically impossible for the recipient to process each signal purposefully (Steigenberger and Wilhelm, 2018). Noise factors thus lead to information distortion, which then limits the effectiveness and efficiency of the signaling process (Yao *et al*., 2018). As a voluntary initiative, ESG reporting by companies is yet to be fully standardized and shows significant variabilities and differences across the three areas (environmental, social and governance) in terms of content and style (Tamimi and Sebastianelli, 2017). Further, companies can selectively disclose positive information and conceal negative information to create a misleadingly responsible image to stakeholders (Marquis *et al*., 2016). From a signaling perspective, this indicates a complex environment full of distorting noises that restrict signal observability and strength (Yao *et al*., 2018), which makes it extremely challenging for the signal recipient to filter the abundant information and grasp the useful message for decision-making.

The role of noise in the environment has received significant attention in empirical studies that deal with information sharing and processing. For instance, Lester *et al.* (2006) discuss how the signaling environment may influence the effect of top management team characteristics and initial public offering investor valuations of the firm. They acknowledge that in uncertain and complex environments, firms are forced to deal with more and conflicting information from a wider range of stakeholders, which is a difficult task and can jeopardize the signaling process. Steigenberger and Wilhelm (2018) challenge the traditional signaling theory in terms of its implicit emphasis on the recipient processing isolated signals. They find empirical evidence that different signals within the signal portfolio interact with each other and jointly affect the signaling outcome. Overall, noise in the environment affects the observability and strength of the signal and increases the recipient's need for information processing. When false signals are mixed in the bundles, the environment is also conducive to inaccurate interpretations and wrong reactions (Friske *et al*., 2023). Therefore, the signaling process is more effective when the signal is stronger relative to noise. We propose that:

H3: The negative association between SCT-ESG and the bullwhip effect is stronger when the signal is stronger relative to noise in the environment.

5. Methodology

5.1 Sample

The conceptual model proposed is tested with Chinese listed firms over the period of 2012–2021. The CSMAR database, one of the largest and most reliable databases for China listed firms, is used to match suppliers and customers listed on Shanghai Stock Exchange and Shenzhen Stock Exchange. Special treatment (ST) or *ST companies are excluded from our sample since they are experiencing financial issues which may have an abnormal influence on our results. Using the top five suppliers and customers disclosed in the focal firm's annual report, we can match the supplier-customer dyads. As a result, a dataset of 1,360 focal firms, 8,773 focal firm – supplier dyads, 953 extended focal firm – tier 1 supplier – tier 2 supplier triads, and 4,443 customer – focal firm dyads is obtained. We then match ESG disclosure scores for all 1,360 focal firms' tier 1 and tier 2 suppliers using the Wind database, which is widely used in OSCM, finance and accounting research due to the richness of data it provides (e.g., Chen *et al*., 2022; Wang *et al*., 2023). It extensively gathers data of listed firms' ESG practices from 2018 through direct communications and other sources such as corporate sustainability reports, regulatory filings, web pages, and news articles. The Wind ESG disclosure score ranges from 0 to 5, where 0 refers to companies with zero ESG information disclosed, and 5 represents those that disclose all indicators outlined by Wind. Other information related to the focal firms, their suppliers and customers is collected from CSMAR database and is minorized at 1% and 99% quantiles. After dropping firms with missing data, our final sample includes 1,213 firm-year observations across four years, consisting of 520 firms across 63 different industries. Appendix A presents the sample distribution by three-digit CSRC industry code.

5.2 Measures

5.2.1 Dependent variable

The independent variable in our study is the bullwhip effect (*Bullwhip*), which is developed based on firm level production variance/demand variation ratio (*AR*). Following Shan *et al*. (2014), we use quarterly financial statement data to calculate the production and demand variation of the focal firm, and measure the bullwhip effect as the *AR* of suppliers relative to that of customers. Therefore, *AR* and supply chain bullwhip effect in a given year are calculated as follows:

$$AR_{i,t} = \frac{\sigma(Production)_{i,t}}{\sigma(Demand)_{i,t}} \quad (1)$$

$$Bullwhip_{i,t} = \frac{AR_{\text{supplier}}}{AR_{\text{customer}}} = \frac{\sigma(Production)_{supplier}/\sigma(Demand)_{\text{supplier}}}{\sigma(Production)_{customer}/\sigma(Demand)_{\text{customer}}} \quad (2)$$

$\sigma(Production)_{i,t}$ is the standard deviation of quarterly production and $\sigma(Demand)_{i,t}$ is the standard deviation of quarterly demand for a firm in a given year. Following Zhao *et al*. (2019), the cost of goods sold is used as a proxy for customer orders or demand, and the sum of cost of goods sold and inventory changes for production. Based on Shan *et al*. (2014), Cachon *et al.* (2007) and Bray and Mendelson (2012), we use Equation (1) to indicate the production variance/demand variation ratio of the focal firm. Inspired by Yang *et al.* (2020), Equation (2) shows the upstream production/demand variation ration relative to that of the downstream supply chain. Therefore, if *Bullwhip* is greater than 1, the amplification of demand upstream the supply chain exists.

5.2.2 Independent variable

The independent variable in our study is SCT-ESG, which we operationalize as ESG disclosure. Since 2018, the Wind ESG Rating has been collecting ESG information on a yearly basis. The rating currently covers more than 8,000 companies, including all Chinses firms listed in "China A-shares" and Hong Kong. Referring to international standards and guidelines such as ISO 26000, there are 25 main categories in the rating with over 2,000 different data points, including staff training, turnover, number of environmental spills, gas emission, etc. Our study uses collective ESG disclosure (*ESG*), an indicator of aggregate ESG information that a focal firms' supply chain members (including their top 5 suppliers and customers and any tier 2 suppliers with a Wind ESG disclosure score greater than or equal to the industrial median) disclose to the public, to measure SCT-ESG, following Gualandris *et al*. (2021).

5.2.3 Moderating variables

This study includes digitalization of the focal firm (*Digitalization*, measured by its use of digital technologies) and signal strength relative to noise (*Signal_to_noise*, measured by signal-to-noise ratio) as moderators. Text analysis is performed on annual reports based on a dictionary of digital technologies (Appendix B), and we use counts of key terms in annual financial reports as a proxy for digitalization (Chen and Srinivasan, 2022). Inspired by Faruquee *et al.* (2021), a dummy variable *Digitalization* is constructed, which equals to 1 if any digital technology terms have appeared in the annual report for a given year, and 0 otherwise. Following Gualandris *et al*. (2021), *Signal_to_noise* is computed as the percentage of average ESG disclosure among supply chain members of a focal firm and the ESG disclosure S.D. in the same set (noise).

5.2.4 Control variables

Following Gualandris *et al*., (2021), Shan *et al*. (2014), and Cachon *et al*. (2007), we control factors that could influence the firm's production, demand and the bullwhip effect, including the firm's operations time (*Age*), total assets (*Size*), debt to total assets ratio (*Leverage*), market to book ratio (*MB*), gross profit rate (*Grossprofit_rate*), state ownership (*SOE*), CEO duality (*Duality*), inventory turnover days (*InvDays*) and accounts payable turnover days (*ApDays*). Since supply chain structure could also affect information flow in the supply chain, we follow De Stefano and Montes-Sancho (2023) and include an indicator of supply chain structure, i.e., supply chain concentration, as another control variable. A detailed description of variables is provided in Appendix C.

5.3 The empirical model

The three hypotheses are formulated into the following OLS models:

$$AR_{i,t} = \frac{\sigma(Production)_{i,t}}{\sigma(Demand)_{i,t}} \quad (1)$$

$$Bullwhip_{i,t} = \frac{AR_{\text{supplier}}}{AR_{\text{customer}}} = \frac{\sigma(Production)_{supplier}/\sigma(Demand)_{\text{supplier}}}{\sigma(Production)_{customer}/\sigma(Demand)_{\text{customer}}} \quad (2)$$

$$AR_{i,t} = \beta_{10} + \beta_{11} ESG_{i,t} + \beta_{12} \sum Controls_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$Bullwhip_{i,t} = \beta_{20} + \beta_{20} ESG_{i,t} + \beta_{22} \sum Controls_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$AR_{i,t} = \beta_{30} + \beta_{31} ESG_{i,t} + \beta_{32} Digitalization_{i,t} + \beta_{33} ESG_{i,t} * Digitalization_{i,t} + \beta_{34} \sum Controls_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$Bullwhip_{i,t} = \beta_{30} + \beta_{41} ESG_{i,t} + \beta_{42} Signal\_to\_noise_{i,t} + \beta_{43} ESG_{i,t} * Signal\_to\_noise_{i,t} + \beta_{44} \sum Controls_{i,t} + \varepsilon_{i,t} \quad (6)$$

$$AR_{i,t} = \beta_{50} + \beta_{51} ESGe_{i,t} + \beta_{52} Digitalization_{i,t} + \beta_{53} ESG_{i,t} * Digitalization_{i,t} + \beta_{54} \sum Controls_{i,t} + \varepsilon_{i,t} \quad (7)$$

$$Bullwhip_{i,t} = \beta_{50} + \beta_{51} ESG_{i,t} + \beta_{52} Signal\_to\_noise_{i,t} + \beta_{53} ESG_{i,t} * Signal\_to\_noise_{i,t} + \beta_{54} \sum Controls_{i,t} + \varepsilon_{i,t} \quad (8)$$

where *AR* refers to the variation of production to variation of demand ratio of the focal firm. *Bullwhip* refers to the supply chain (suppliers to customers) bullwhip effect in a given year. *ESG* is the percentage of supply chain members of a focal firm that have an ESG disclosure score higher than or equal to the industrial median in a given year. *Digitalization* refers to the application of digital technology by a focal firm in a given year, and S*ignal_to_noise* is the ratio between the average (signal) and the SD (noise) of ESG disclosure scores of supply chain members in a given year. *Controls* is the set of control variables explained above. It is worth

noting that we do acknowledge the potential biases these proxies could cause to the results (Cachon *et al*., 2007; Zhao *et al*., 2019).

6. Analysis and results

6.1 Descriptive statistics

Descriptive statistics of the final sample are summarized in Table 1. Evidently, the mean value of *AR* stands at 3.07, which is greater than 1, indicating that at the firm level, production variation exceeds demand variation. Therefore, changes to inventory exist. Additionally, the mean value of *Bullwhip* (6.0) surpasses 1 and that of *AR*. This means that the difference between production variance and demand variance of the firm is amplified from the downstream supply chain to the upstream, which further confirms the presence of the bullwhip effect in the supply chain. The standard deviation of *Bullwhip* is high (35.06), which demonstrates significant disparities in operational efficiency among firms. The mean value of *Digitalization* is 0.77, indicating over three quarters of firm-year observations are, at least to some extent, digitalized.

Table 1 also presents correlations among key variables and provides preliminary evidence for the main hypothesized relationships. As shown, *ESG* is negatively and significantly correlated with both *AR* (b=-0.109, p<0.01) and *Bullwhip* (b=-0.088, p>0.1). However, its negative association with *Bullwhip* is not significant at 90% confidence interval, which requires further validation through regression analysis.

[Table 1]

6.2 Results of hypothesis testing

Ordinary least squares (OLS) regressions are then performed to assess the hypothesized relationships, and the results are presented in Table 2. The effect of SCT-ESG (*ESG*) on *AR* is assessed with potential year and industry effect controlled. Models 1 and 3 reveal a negative coefficient between *ESG* and *AR*, with or without the presence of control variables (b = -0.168, p < 0.05; b = -0.193, p < 0.01 respectively). Similarly, Model 2 demonstrates a negative association between *ESG* and *AR* when the year effect is not controlled (b = -0.189, p < 0.01). This highlights the robust negative effect of SCT-ESG on the focal firm's variation of production to variation of demand ratio, which is unlikely to be affected by other factors. At the supply chain level, a negative relationship between *ESG* and *Bullwhip* is observed in Model 4 (b = -1.236, p < 0.01). When the year and industry effects are controlled (Model 6), the negative association is further strengthened (b = -1.895, p < 0.01 respectively). The omission

of the year effect does not significantly impact the result (b = -1.980, p < 0.01). Therefore, our statistical analysis provides strong support for H1.

Regarding the proposed moderating effects, Models 1 and 3 in Table 3 reveal that the coefficients between the *ESG*Digitalization* and *AR* (b=-0.103, p<0.1) and *Bullwhip* (b=-0.829, p<0.05*)* are both negative and significant without considering the effect of control variables. When control variables are integrated into the analysis (Models 2 and 4), the effect of *ESG*Digitalization* on *AR/Bullwhip* remains significantly negative (b=-0.160, p<0.01; b=-1.483, p<0.01, respectively). Therefore, digitalization of the firm works as an effective moderator in the negative association between SCT-ESG and the bullwhip effect. Therefore, we find statistical support for H2.

Similarly, Models 5 and 7 in Table 3 demonstrate that the association between *ESG*Signal_to_noise* and *AR/Bullwhip* is negative and significant (b=-0.119, p<0.05; b=-0.496, p<0.01, respectively) when control variables are not accounted. According to Models 6 and 8, when the potential effect of control variables is taken into account, the negative association between *ESG*Signal_to_noise* and *AR/Bullwhip* remains significant (b=-0.155, p<0.05; b=-4.022, p<0.001, respectively). Therefore, the strength of the signal relative to noise in the environment is proven to play a moderating role, and H3 is supported by the statistical results.

[Tables 2 & 3]

6.3 Endogeneity

To address potential endogeneity, we employ two-stage least squares regressions with instrumental variables (2SLS-IV). Two instrumental variables related to ESG disclosure are identified, i.e., ESG investment and ESG committee set-up. According to Gillan *et al*. (2021), ESG investment funds play an important role in firms' ESG performance and information disclosure. However, as fund managers make independent decisions, the investments are unlikely to directly influence the firm's operational performance. Following Fatemi *et al*. (2018), we regard executive members' working experience in CSR/ESG-related roles as evidence of ESG committee set-up in the company. Dhaliwal *et al*. (2012) highlight that firms with ESG committees are more likely to disclose ESG-related information and their disclosures tend to be more reliable. Therefore, these indicators are appropriate instrumental variables that can predict a firm' ESG disclosure but not the bullwhip effect.

Table 4 presents the result of the 2SLS-IV estimation. First, we regress *ESG* on ESG investment, ESG committee and other control variables. Models 1 and 2 in Panel A indicate significant positive correlations between the instrumental variables and *ESG*. We also use over-identifying restriction estimation to test the validity of instrumental variables, and the Hansen J test indicates that our instruments are exogeneous. The results of partial F-statistic are greater than 10, indicating relatively strong rather than weak instrument variables (Woolridge, 2015). The second stage of the 2SLS estimation is displayed in Panel B of Table 4. In Models 3 and 4, the coefficient estimates of *ESG* on *AR* and *Bullwhip* are both negative and statistically significant at 5% level. These results are consistent with the main analyses.

[Table 4]

To address the potential sample selection bias issue, we further apply the propensity score matching (PSM) method to match each treatment firm (i.e. a firm with above the year-industry ESG score) with a control firm that had a similar propensity as the treatment firm but got the below year-average ESG score (Camuffo and Poletto, 2023; Xiong *et al.*, 2021). The matching procedure helps to ensure that firms in the treated and control groups have almost the same characteristics, which may potentially influence the firm bullwhip performance. To implement PSM, a binary logit model with the dummy dependent variable, indicating whether a firm is above the year-industry ESG score (code 1) or below (code 0), has been applied. The covariates used in the logit model were a set of firm organizational, operational, managerial and supply chain structure characteristics, e.g., firm age, size, duality, inventory turnover days, and supply chain concentration. As shown in Panel C of Appendix D, the means of most independent variables between treat and control groups are not significantly different, confirming the similarity between two groups and demonstrating the matching quality. After identifying treatment and matched control firms, we apply the data to Models (6) and (8). According to Table 5, the coefficients of interactions are always negative at 5% or lower significant levels, which supports that ESG disclosure together with digitalization or signal-to-noise reduces the bullwhip effect. Overall, we conclude that the empirical analysis does not appear to be affected by endogeneity and sample selection bias.

[Table 5]

6.4 Robustness checks

To check the robustness of results, we apply alternative proxies for collective ESG disclosure and digitalization for H1 and H2. We follow Gualandris *et al.* (2021) to replace ESG disclosure

in the baseline model with the collective environmental disclosure. As shown in Models 1, 2 and 3 in Table 6 Panel A, *Alternative_ESG* is negatively correlated with *AR* at 5% significant level (b = -0.197, $p < 0.01$; b = -0.161, $p < 0.05$; b = -0.182, $p < 0.05$ respectively). Similarly, *Alternative_ESG* is negatively related to *Bullwhip* in Models 4, 5 and 6 (b = -1.699, $p < 0.01$; b = -1.852, $p < 0.01$; b = -2.225, $p < 0.01$ respectively).

We also apply an alternative proxy focusing on the frequency of digital technologies mentioned by the executives in the company's annual report. We use the same dictionary of digitalization terms (Appendix B) but now focus on the change of the number of terms. If there is an increase in the number of terms, we will code the dummy variable *Alternative_Digitalization* as 1 (otherwise 0), because it is an active signal for the firm's digitalization strategy. In Models 7, 8 and 9 in Table 6, the coefficients of the interaction term *ESG*Alternative_Digitalization* are all significant and negative for *AR* (b = -0.099, p < 0.1; b = -0.134, $p < 0.05$; b = -0.140, $p < 0.01$ respectively). Similarly, Models 10, 11 and 12 report negative coefficients for *ESG*Alternative_Digitalization* and *Bullwhip*. Therefore, the results of the main analyses are considered robust.

[Table 6]

7. Discussions

Drawing upon the key tenet of the signaling theory, our study empirically confirms that the bullwhip effect can be reduced with SCT-ESG, a transparent supply chain where non-financial information (i.e., ESG) is disclosed by multi-tier supply chain members. Despite the conceptual and practical overlaps, studies on SCT and ESG are separated in the literature. While existing SCT literature calls for the sharing of more supply chain information to external stakeholders (Schäfer, 2023), discussions on ESG focus on the outcomes of voluntary disclosure mainly from accounting and marketing studies (e.g., Baumgartner *et al*., 2022; Friske *et al*., 2023). Recently, despite the growth of interests on ESG disclosure in OCSM studies (e.g., Lam, 2018; Song *et al*., 2023), it has not been fully discussed in a SCT context, and advancements in both fields are ill-integrated. For instance, while it is proven that SCT has a range of operational benefits (Montecchi *et al*., 2021), outcomes of ESG disclosure are mostly strategic at the firm level (Lam, 2018; Friske *et al*., 2023; Song *et al*., 2023). Therefore, our study bridges these two streams of literature and delves deeper into the operational implications of SCT-ESG.

A novel finding of our study is the negative effect of SCT-ESG on the bullwhip effect experienced at the supply chain level. At the same time, individual firms experience a reduced

production variation/demand variation ratio and thus less inventory fluctuations. Overall, prior studies generally acknowledge the existence of bullwhip effect in supply chains, and discussions on its mitigation are pointing to the sharing of information between organizations (e.g., Wang and Disney, 2016; Hofmann, 2017). However, information sharing for reducing the bullwhip effect focuses on operational information, such as data on existing and predicted inventory, sales, order, production and delivery (Wang and Disney, 2016), which has not considered non-operational/financial information such as ESG. Non-financial indicators are increasingly deemed crucial as they signal an organization's integrity, risks, and possible future prospects, which can affect external stakeholders' behaviors (Crifo *et al*., 2015). Looking beyond the organizational boundary, as stakeholders increasingly value sustainability and business integrity, SCT-ESG establishes trust among supply chain members and with external stakeholders, provides a platform for information sharing, and builds a reference framework to assess the likelihood of supply chain disruptions caused by irresponsible behavior (Lam, 2018). With the knowledge of "what is happening in the upstream and downstream" of the supply chain, the company has the confidence to reduce the need for excessive buffer inventories (Zhao *et al*., 2019). Therefore, SCT-ESG serves as an effective signal of supply chain operations, which, not only benefits outsiders such as investors, but also organizations within the supply chain.

Our study builds on and extends the signaling theory by adding contextual factors that can affect the signaling process and outcome. We find that when the focal company is digitalized, the signaling process of SCT-ESG is more effective and the signaling outcome (in terms of the reduced bullwhip effect) is boosted. Digitalization has been widely studied in the OSCM literature with consistent findings on their positive roles (e.g., Zhao *et al*., 2023; Li *et al*., 2023). Digitalization is considered valuable for organizations especially in today's highly unpredictable business environment due to its positive effect on organizational learning and key capabilities building, such as adaptability, agility and networking (Ribeiro-Navarrete *et al*., 2021; Li *et al*., 2023). In a supply chain with ESG transparency, digital solutions play an irreplaceable role for signal recipients to filter the complex environment and grasp the critical signal. With the help of digital tools, the firm can make data-driven production planning, minimizing the amount of buffer stock. When more supply chain members are digitalized, they can communicate more efficiently through electronic linkages, reducing the bullwhip effect on the supply chain scale (Yao and Zhu, 2012).

At the other end of the signaling process, the signal sender has to make sure that the signal is clear and strong enough to stand out among other information and noise factors. Fundamentally, the signaling theory centers on reducing the information asymmetry between parties through the signal (Connelly *et al*., 2011). Companies voluntarily disclose ESG information, aiming to enhance SCT and external stakeholders' understanding of their unobserved quality (e.g., ESG practices, values, commitments). However, the effectiveness of this information sharing also depends on the signaling environment, where a number of factors could affect the credibility and strength of the signal (Connelly *et al*., 2011). Signals must be strong and observable so that the recipient can perceive it and respond to it (Song *et al.*, 2023). SCT-ESG enables multiple supply chain members to disclose the information at the same time but at varying degrees, and the signaling process and outcomes are optimized when the signals are stronger relative to noise.

7.1 Research implications

The empirical evidence generated from our study has successfully materialized the intended contributions outlined earlier. Specifically, our study has three main implications to existing research. First, the result of our study contributes to the ongoing explorations on SCT and inspires future research to broaden the scope of SCT. Among all types of information disclosed for SCT, our study focuses on an emerging area, i.e., SCT-ESG, and empirically confirms its operational benefits in terms of operational efficiency at both organizational and supply chain levels. While companies are increasingly disclosing information regarding their products, governance, finance, and sustainability to external stakeholders, the actual benefit of the disclosure remains unclear in need of more empirical evidence (Sodhi and Tang, 2019). Our study calls for works to conceptualize SCT and empirical investigations on its outcomes.

Second, our study supplements existing ESG disclosure literature and serves as a bridge to connect it with the SCT literature. Existing studies show a positive effect of corporate responsibility disclosure and inclusive environmental disclosure on financial performance (Longoni and Cagliano, 2018) and risk performance (Lam, 2018) of the firm. While these studies are essential in motivating SCT, they have taken an organizational perspective, thus limiting the outcome of SCT-ESG to the organizational level. Our study encourages further works on ESG disclosure to take a wider perspective (i.e., the supply chain) and enhance the depth of understanding of its outcomes. On the one hand, improved organizational performance driven by SCT-ESG can be further disseminated into functional departments of the organization and affect functional decision-making and performance. On the other hand, when

this happens across multiple organizations, the supply chain operational performance can be improved. A transparent supply chain provides opportunities for individual and collective performance improvement for those involved, and SCT-ESG can benefit overall supply chain operations. This, of course, will need further empirical support.

Third, we extend the application of the signaling theory in OSCM through incorporating contextual factors that affect the signaling effectiveness. While the signaling environment and signal characteristics are considered crucial elements of the theory, they are under-researched in empirical studies so far (Connelly *et al*., 2011). Former studies tend to assume that the sending of the signal by the sender and the interpretation of it by the recipient is a straightforward process, which has oversimplified the process and neglected the complexity of the signaling environment. Our result highlights the factors from both the sender's and the recipient's ends to boost signaling effectiveness. On the one hand, the sender has to make sure that the signal is stronger relative to other information and noise. In an ESG transparent supply chain with a lack of reporting standards and formats, signal observability is seriously limited, making it challenging for the recipient to notice the signal and process information (Bafera and Kleinert, 2023). Consequently, the desired signaling outcome cannot be guaranteed. On the other hand, from the recipient's perspective, it is important to develop digitalization capabilities and apply digital tools such as big data analytics to make data-driven decisions (Li *et al*., 2023b). We acknowledge the existence of other factors that could affect the signaling process and hope to open the door for more creative and in-depth applications of the signaling theory in OCSM focusing on contextual factors.

7.2 Managerial implications

Our study offers valuable practical implications to supply chain managers. First, disclosing ESG information is believed to be a useful communication tool that makes the company more transparent about opportunities and risks external stakeholders may face by interacting with the organization. Experts urge companies to embrace the existing reporting standards and make use of information disclosed by other companies (Adcock, 2021). In addition to the growing demand from investors for ESG disclosure, our study shows that when more actors in the supply chain actively disclose ESG information, the operational efficiency of the firm and the supply chain will improve. However, this benefit may not be realized automatically when companies engage in ESG reporting and will require active scanning of information shared by others in the supply chain to understanding both explicit and implicit messages it conveys. Therefore, supply chain managers are encouraged to adopt existing ESG reporting standards to

improve their own transparency to others, and deploy transparency provided by others for decision-making.

Second, our study shows the importance of digitalization for effective and efficient data analysis in complex situations such as a transparent supply chain. In the digital age, the existence of big data has made manual comprehension impossible, and digital technologies such as AI, IoT and the cloud are needed by organizations to optimize their operations. Supply chain managers are therefore actively encouraged to utilize digital tools available to store, share and make sense of data.

7.3 Limitations and future research

Notwithstanding the contributions, our study has some limitations that can inspire future research directions. First, our study focuses on one aspect of SCT, i.e., SCT-ESG. It would be valuable for future studies to consider a wider scope of information disclosure when investigating SCT. For instance, studies are encouraged to include both financial/operational and non-financial indicators at the same time, and study how such transparency affects performance. Second, SCT researchers are encouraged to further advance our understanding of positive and negative results of higher transparency. Our study focuses on one operational aspect, i.e., the bullwhip effect. Future studies can look at operational performance as a whole, or other elements such as quality and dependability. Third, our sample is limited to a single country context, i.e., China, which may cause generalizability issues of findings. Researchers are thus encouraged to carry out cross-country studies in the future. Last, our study focuses on moderating factors that affect the strength of the ESG-bullwhip effect relationship. As a complex relationship that is not straightforward, more studies, both exploratory and explanatory, are needed to investigate the mechanisms through which ESG disclosure affects the bullwhip effect, preferably from different theoretical lenses.

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