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Diffusion of labor standards through supplier–subcontractor networks: An agent-based model

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Abstract

Subcontracting represents a popular business model in supply chains across industries. In the case of hidden subcontracting, subcontractors are beyond the visible horizon of the (focal) buying firm. Hence, buyers must rely on a cascading effect for diffusing practices such as compliance with labor standards through their supply networks. Motivated by the case of the Bangladeshi garment industry, we constructed an agent-based model with buyers, first-tier suppliers, and subcontractors as agents in a supply network in order to study the impact of network characteristics on the diffusion of labor standards. Our model followed a power-based diffusion rule that emphasized the coercive power that buyers use to pressure their suppliers into adopting labor standards. This rule is a key underlying assumption of compliance-based supplier management. Hypotheses regarding power asymmetries through centrality and density of specific network components, as well as structural elements of the network, such as complexity and distance, were tested for different industry scenarios. Our analysis demonstrated that network asymmetries have ample negative effects on the adoption of labor standards, whereas complexity plays a minor role. Moreover, the impact of the tested structural determinants for sustainability diffusion was found to be contingent on specific industry types in the garment industry. This paper discusses its findings in light of previous research on subcontracting and multitier supply chain management. Among others, we highlight how subcontracting increases horizontal complexity at each supply chain tier, and how intermediaries such as *sustainability nexus suppliers* may crucially affect the adoption of labor standards within industries.

KEYWORDS
agent-based modeling, network asymmetries, standard diffusion, subcontracting, supply networks, sustainable supply chain management

1 | INTRODUCTION

Subcontracting is prevalent in supply chains across various industries, but it has attracted little attention in the scholarly discourse as of yet. In the case of hidden or unauthorized subcontracting, subcontractors are beyond the visible horizon of (focal) buying firms (Carter, Rogers, & Choi, 2015); this means that buyers cannot directly control subcontractor operations (Huang, Song, & Swinney, 2017). At the same time, there is increasing pressure on businesses to contribute to sustainability standards beyond factory gates or organizational boundaries and to assume responsibility for the conduct of the entire supply and demand chain (Arnold & Bowie, 2003; Blass & Corbett, 2018; Hartmann & Moeller, 2014). Customers and other stakeholders make buyers accountable for labor rights violations and exploitative working conditions, such as child labor (Gomez-Paredes et al., 2016) and forced or slave labor (Gold, Trautrims, & Trodd, 2015), no matter where in their supply networks they might occur (Gold & Heikkurinen, 2018). This motivates focal buying firms to cascade labor standards throughout their supply networks. While there is some evidence that this cascading effort often fails (Villena, 2019), there is generally limited knowledge about the mechanisms that spread labor standards through supply networks.

Early research addressed the question of how sustainability-related management systems standards are diffused (e.g., Corbett & Kirsch, 2001). Later on, the question of how sustainability spreads along supply chains and networks gained academic attention (e.g., Marshall, McCarthy, Claudy, & McGrath, 2019), although studies on the diffusion of sustainability along multiple tiers of supply chains remain scant. Even more limited is research that covers the phenomenon of subcontracting in supply networks (Caro, Lane, & Saez de Tejada Cuenca, 2019; LeBaron, 2018). This is astonishing since subcontracting represents a highly relevant phenomenon in the goal of sustainability in supply networks; such practice may substantially enhance complexity and blur the visible horizon of focal companies (Carter et al., 2015) even if only a few supply chain tiers are involved. Our study examined supplier–subcontractor networks in which the buyers do not hold direct contractual relationships with (all) the companies that produce their purchase. It employed an agent-based modeling approach with a diffusion mechanism based on an imbalance of power and the resulting network asymmetries (Prado & Woodside, 2015) to analyze the effects of network centrality, density, complexity, and distance on the spread of labor standards in such networks. Our study addressed the following research question: How do key structural network characteristics affect the diffusion of labor standards from buyers throughout a supplier–subcontractor network?

We drew on the conceptualization of power and network characteristics to examine subcontracting in the Bangladeshi garment industry, as described by Labowitz and Baumann-Pauly (2014) and Caro et al. (2019). These authors studied the sector and found that different forms of subcontracting have long been essential features of this industry; they are particularly rooted in structural problems arising from exploitative pricing and procurement practices (Alamgir & Banerjee, 2019) and lead to severe violations of labor standards. Even though focal firms have strived to improve working conditions in supplier companies, for example, through supplier codes of conduct and auditing (Toffel, Short, & Ouellet, 2015; Villena, 2019), hidden subcontracting in apparel supply networks makes it impossible for foreign buyers to track where—and under which conditions—products are actually manufactured (Caro et al., 2019). Beyond the case of Bangladesh's garment industry, subcontracting is a common business model in supply chains across various industries. Focal buying companies themselves have given rise to high levels of subcontracting in labor-intensive supply chains as they have moved to arm's length contractual agreements with suppliers to cut costs and reduce legal ownership (LeBaron, 2014). This gives rise to the question of how far corporate responsibility for labor conditions can be (re)extended within supply networks.

Supporting the normative stance of industrial ecology research (Ehrenfeld, 2007), labor issues have recently entered the debate on life cycle sustainability assessment (Wulf, Zapp, Schreiber, Marx & Schloer, 2017) under the label of "social life cycle assessment" (Kuehnen & Hahn, 2017). An investigation of hydrogen production by advanced alkaline water electrolysis and its effects on working conditions, for instance, pointed to adverse impacts on global upstream supply chain stages (Werker, Wulf & Zapp, 2019). The current study investigates the diffusion of labor standards through supply networks with a special focus on network characteristics and power. The remainder is structured as follows. The next section addresses the diffusion of (social) sustainability in supply networks. After deriving hypotheses from the literature and presenting the diffusion model, the results of four industry scenarios are reported and discussed. The conclusion points to the study's limitations, directions for future research, and managerial implications.

2 | DIFFUSION OF SUSTAINABILITY ALONG SUPPLY NETWORKS

The question of how standards are diffused has gained scholarly attention in recent decades, particularly with regard to quality and environmental management systems standards (Castka & Balzarova, 2008; Corbett, 2006; Corbett & Kirsch, 2001). Rosen, Beckman, and Bercovitz (2002) have stressed that standards may help transaction cost reduction and effective goal attainment across companies if government regulation and other shared norms are missing. While early studies have focused on the adoption of sustainability at the firm and sometimes at the supplier level (Rock, Lim, & Angel, 2006), recent research interest has focused on sustainability diffusion in multitier supply chains (e.g., Grimm, Hofstetter, & Sarkis, 2014; Tachizawa & Wong, 2014; Wilhelm, Blome, Wieck, & Xiao, 2016) and supply networks (e.g., Moreno-Camacho, Montoya-Torres, & Jaegler, 2019; Villena & Gioia, 2020). However, research on the diffusion of sustainability along supply chains is still in its infancy and is dominated by qualitative and conceptual approaches; it only occasionally considers issues of supply network characteristics. For example, Wilhelm et al. (2016) identified supply chain complexity as an important and highly differentiated contingency factor of buying firms' sub-supplier management. Furthermore, Tachizawa and Wong (2015) looked at supply network characteristics when analyzing conceptually how supply network complexity, centralization, and density moderate the relationship between green supply chain governance and environmental performance.

While such conceptualizations assume symmetrical responses to governance mechanisms for standard adoption and non-adoption in the network, causal asymmetry might alter the conditions for the dissemination of labor standards (Prado & Woodside, 2015). For instance, a high degree of standard adoption already at the first-tier supplier level might represent a necessary but insufficient condition for a wider spread of the standard, depending on network configurations. Similarly, Ayuso, Roca, and Colome (2013) found evidence that customer-induced sustainability requirements are asymmetrically transmitted throughout the supply chain, with large buying companies imposing sustainable practices more strongly than smaller companies. Although these kinds of size asymmetries do not comprehensively account for the barriers to standard diffusion in supply networks, they provide a starting point for further model-based investigations.

Besides structural network characteristics, the concept of power (e.g., Cox, 1999; Cox, Sanderson, & Watson, 2001; Maloni & Benton, 2000) has attracted substantial attention in buyer–supplier relationships, since previous studies have provided evidence that the focal firm's power is crucial for diffusing sustainability (e.g., Lee, Klassen, Furlan, & Vinelli, 2014). Grimm, Hofstetter, and Sarkis (2016) found that sub-supplier management was driven by public attention directed toward first-tier suppliers, risks of sub-suppliers' misbehavior, and the focal company's channel power. However, power effects can contradict or even cause supply chain strategies and related governance mechanisms to backfire (Plambeck & Taylor, 2015). Touboulic, Chicksand, and Walker (2014) showed that power imbalances can be leveraged to push sustainability practices through the supply chain, at least in the short term. In the long run, however, the "use of buyer power on dependent suppliers creates resistance, which impairs the long-term achievement of sustainability goals" (Touboulic et al., 2014, p. 604), and might be seen as impairing suppliers' willingness to diffuse sustainability standards further up the supply chain (see also Hall & Matos, 2010).

Building on this work, Marshall et al. (2019) investigated which types of power make first-tier suppliers adopt socially responsible procurement practices. They found that it is indeed expert and referent power that foster the adoption; in contrast, not all forms of power that imply the direct action of one party on another party (e.g., coercive, legitimate, and reward power) have positive effects on the adoption decisions. Therefore, buying firms can enhance the chances that first-tier suppliers will engage in socially responsible procurement practices themselves if they provide respective expertise, training, and knowledge, as well as values and orientation toward sustainability, rather than bullying or bribing suppliers. Beyond the assumption of power to assure the compliance of suppliers with regard to labor standards, however, the diffusion of sustainability practices requires accompanying commitment-oriented means such as joint problem-solving or information exchange to reach the full potential of private (voluntary) regulation (Locke, Amengual, & Mangla, 2009). To promote diffusion of sustainability through supply networks, Villena (2019) as well as Villena and Gioia (2020) highlighted the strategic role of the buyer's procurement function that has to engage with internal and external stakeholders as well as directly with the supplier's procurement unit.

We concede that the proposed conceptualization of power and network characteristics omitted the means of buyer engagement with and commitment toward first-tier suppliers; this is a considerable limitation. Instead, our approach provided the foundation for a model-based evaluation of power-based interaction in supply networks. We only covered one form of power, namely, coercive relational power; our neglect of other forms of power, such as referent and expert power, is also a limitation (Marshall et al., 2019). Our diffusion was based on penalties, which could be conceived as negative rewards (Porteous, Rammohan, & Lee, 2011), but not as voluntary measures (Rosen et al., 2002). We assumed that the governance of suppliers based on monitoring, control, and threats of penalties is a common form of supply chain management (Lund-Thomsen & Lindgreen, 2014).

Recent literature has also more broadly explored the role and agency of various types of intermediaries in diffusing good labor practices through international supply networks. Munir, Ayaz, Levy, and Willmott (2018) scrutinized how corporate, state, multilateral, and civil society actors have served as intermediaries in global production network (GPN) governance. More closely related to our study's focus, Soundararajan, Khan, and Tarba (2018) highlight the role of sourcing agents as boundary spanners between Western buyers and local suppliers who contribute to labor standards in the Indian garment industry. Building on this, the present research studies, among other things, the role of first-tier suppliers as intermediaries to diffuse labor standards from the focal buying company toward subcontractors.

3 HYPOTHESES DEVELOPMENT

Lee et al. (2014) stated that the stringency of sustainability requirements tends to increase as they pass upstream in the supply chain. Sustainability-oriented organizations are able to force their suppliers to change their working conditions if the balance of power in the supply relationship is tipped in their favor. In this study, we conceived of power, in an overarching sense, as the ability of one party to impose its will over another party (cf., Emerson, 1962). Accordingly, good labor practices were driven by power and control in our model rather than mutual and voluntary intentions. Related measures of power can be drawn from resource dependence theory, which explains how critical external resources influence organizational interdependence and behavior (Casciaro & Piskorski, 2005; Hillman, Withers, & Collins, 2009). Both aspects of interdependence—power imbalance and mutual dependence—can be found in the buyer–supplier relationship in procurement decisions. As most apparel companies today do not operate their own production facilities but use external suppliers, this access to production capacity at the supplier stage is a crucial part of business success. To acquire control over these supplier resources, buying firms increase suppliers' dependence on them. In the apparel sector, there is usually a rather persistent power imbalance in favor of the buyer with sufficient capacity available in the supply market; this also explains why resource dependence does not lead to formal, permanent interorganizational arrangements but to a system of short-term contracts (Casciaro & Piskorski, 2005). Focal firms, accordingly, lose direct control when suppliers outsource (parts of) their assignment to subcontractors. This is particularly true for hidden subcontracting as observed in Bangladesh's garment industry (Padmanabhan, Baumann-Pauly, & Labowitz, 2015).

According to resource dependence theory, firms purposefully try to increase the dependence of external business entities upon themselves or decrease their own dependence upon external environments (Barringer & Harrison, 2000) (e.g., by taking a more central position in the supply network). In this context, centrality can be defined as the extent to which overall connectedness is organized around particular nodes in a network (Borgatti & Li, 2009). Accordingly, a highly central buying firm has more control over formal governance mechanisms, such as sustainability standards, auditing schemes, or codes of conduct, thereby making it more difficult for suppliers and subcontractors to hide bad practices (Orsdemir, Hu, & Deshpande, 2019). Proposing the concept of the nexus supplier, Yan, Choi, Kim, and Yang (2015) argue that suppliers' and subcontractors' criticality arise from their network position and interorganizational ties such that suppliers with high network centrality might cause network asymmetries and are therefore associated with more power. Network density can be seen as another form of power that is derived from network asymmetries. Generally, network density can be defined as the number of total ties in the network compared to the number of potential ties (Borgatti & Li, 2009). Kim, Choi, Yan, and Dooley (2011) assigned a higher density of the supplier network to a higher effort to manage it, in comparison to a loosely connected supplier network. Strong, informal, and therefore hidden ties in supplier–subcontractor networks, such as in Bangladesh's garment industry, are accordingly assumed to cause power asymmetries between the buyer and (nexus) suppliers; this hinders standard diffusion from the buyer. In this context, it is hypothesized that the higher the supplier–subcontractor centrality (SSC) or density compared to the buyer centrality or density, the less likely the standard will be adopted. This leads to the following hypotheses:

H1: Supplier–subcontractor centrality (*SSC*) negatively affects labor standard adoption in supply networks.
H2: Supplier–subcontractor density (*SSDen*) negatively affects labor standard adoption in supply networks.

Besides drawing on power-related arguments, the present study explicitly took a network perspective. Supplier–subcontractor networks may feature high network complexity at the first-tier supplier stage, which the buyer must account for. Generally, complexity is understood as a multidimensional construct that is a function of the number of network actors establishing different types of interrelationships (Choi & Krause, 2006; Tachizawa & Wong, 2015). Organizational design literature distinguishes between horizontal complexity (number of suppliers), vertical complexity (number of "jumps" in the network), and spatial complexity (geographical dispersion of suppliers) (Grimm et al., 2014). Nodes that are short path lengths from other nodes in a network receive information sooner and more effectively than distant nodes (Borgatti & Li, 2009). Long, fragmented supply chains have often been linked to the difficulties of spreading sustainability and labor standards (Alsamawi, Murray, & Lenzen, 2014; Mena, Humphries, & Choi, 2013). Following the concept of the double agency role (Wilhelm et al., 2016), first-tier suppliers have to act as intermediaries to ensure that subcontractors comply with the requirements of sustainability standards under conditions of a limited visible horizon of buyers. Following the previous arguments, we used the number of nodes in the supply network ("horizontal complexity"), the number of jumps ("vertical complexity"), and the average path length within the supplier–subcontractor network ("supply network distance") as proxies for complexity to study the diffusion of power and adoption of standards. Thus, we assumed that complexity increases with the size and distance of the supplier–subcontractor network, thereby hindering the diffusion of labor standards through a supply network. Accordingly, the following hypotheses were formulated:

H3: Horizontal complexity (*HC*) negatively affects labor standard adoption in supplier–subcontractor networks.
H4: Vertical complexity (*VC*) negatively affects labor standard adoption in supplier–subcontractor networks.
H5: Supply network distance (*SNDist*) negatively affects labor standard adoption in supplier–subcontractor networks.

4 | DIFFUSION MODEL

In this section, we present a stylized network-based supplier–subcontractor model. The idea of viewing supply chains and supplier–subcontractor relationships as complex networks is well established (Basole & Bellamy, 2014; Blass & Corbett, 2018). Business units are modeled as nodes (vertices) with connections (edges) representing supply network relationships in a graph $G(V, E)$, where V indicates the vector of tiers (jumps) and E is the set of links among nodes (factories) in the graph. Connections are directional as they represent goods and services being sold by one business to another. Edge weights are used to represent the value of the pieces (garments) being traded. In contrast to other modeling approaches, agent-based modeling takes advantage of its ability to model complex, decentralized systems with heterogeneous, localized decision-making in a network structure where each actor makes its own independent decision instead of following a top-down hierarchy (Serova, 2013). This more accurately reflects the reality of contemporary supplier and subcontractor management (Blass & Corbett, 2018) and avoids the simplifications that are usually needed when mathematical modeling is used to make equations tractable (Borrill & Tesfatsion, 2011).

4.1 | Building the supply network

Sun and Wu (2005) reported that graphs have the following characteristics in building a supply network: preferential attachment and robustness. To achieve these, many papers applying computational methods such as simulation or analytical approaches used off-the-shelf network models to act as their supply network. Nair and Vidal (2011), for example, combined a preferential attachment model and a random model. To create their model, they added nodes to the network, connecting each new node to existing nodes with a probability that was proportional to the number of connections that the existing nodes already had. This is the standard procedure for creating such networks. Xuan, Du, Li, and Wu (2010) also built on this approach by adding overarching growth rules about when new products were created using the existing products and raw materials. However, we did not use such overarching rules–or a God's eye view–to guide preferential attachment. Our network structures were specifically created in the agent modeling environment NetLogo (version 6.0.1); the NetLogo code is given in the supplementary material.

Our network building approach was run in different steps. First, a number of buyers, large supplier factories, and small subcontractor factories were instantiated. The initial numbers of each were varied to depict specific industry scenarios (see Section 4.4). Second, large and small factories were differentiated by capacity, allowing large factories to accept orders up to 10 times their capacity, while small factories could not subcontract. Small factories were not allowed to accept orders beyond their capacity due to the visibility of their capacity limitations. Moreover, small factories would not be considered by large international buyers in the first place, since they do not have the capabilities to pass basic compliance checks. Third, buyers were told how many orders to place. The number and size of the orders did not change once the scenario was set. Buyers then contacted large factories at random to ask whether they could supply. In the last step, large factories tried to subcontract and fulfill the orders they had accepted by asking other factories, large or small, to supply them. The factories then fulfilled their orders and passed their goods along the network. If the factories stayed within capacity and did not subcontract, the supply chain network stayed bipartite. If subcontracting was pursued, complex networks were created as the amount that the buyer ordered increased. In this way, a supply network was simulated based on subcontracting, as described by Labowitz and Baumann-Pauly (2014) as well as Caro et al. (2019).

4.2 | Diffusion mechanism

After the supply networks were set, the diffusion mechanism was run. The diffusion mechanism involved one randomly selected buyer trying to force labor standards through to its first-tier suppliers and their respective subcontractors. The mechanism succeeded if the balance of power was tipped in its favor. Then, any factories that adopted the standards would try to force the factories that supply them to adopt the standards. This continued until all agents that could potentially adopt the standards had been given the chance to do so. Casciaro and Piskorski (2005) posited that power relations in a supply chain dyad call for the simultaneous consideration of the power capability of node *i* in relation to node *j*, in addition to the power capability of node *j* in relation to node *i*. Therefore, our mechanism of diffusion can be described as follows: if it is desired, a buyer *i* can force a factory *j* to adopt standards, if the amount that *i* is beholden to *j*, V_{ij}, is less than the amount that *j* is beholden to *i*, V_{ji}. The values can be calculated as:

$$V_{ij} = \frac{w_{ji}}{\Sigma w_{\rightarrow i}}$$

and

$$V_{ji} = \frac{w_{ji}}{\Sigma w_{j\rightarrow}}$$

where w_{ji} is the value of goods or services that flow from *j* into *i*, $\Sigma w_{\rightarrow i}$ is the total value that flows into *i*, and $\Sigma w_{j\rightarrow}$ is the total value that flows out of *j*. Given this, node *j* will adopt the standards if a relationship it has to any node *i* is such that:

$$V_{ij} < V_{ji}$$

and node *i* has already been adopted[1]. More plainly, a buyer can force a first-tier supplier or a first-tier supplier can force a subcontractor to adopt the standards if the value of the goods or services that flow between them is a smaller ratio of total business for the buying firm than for the supplying or subcontracted firm.

Figure 1 shows a simple example of this mechanism with two unweighted networks. In the network on the left, node 6 wants to push labor standards onto its first-tier suppliers and subcontractors. If every edge is given, and the weight = 1, then the in-neighbors of node 6 will adopt the

[1] We use > rather than ≥ as our assumption is that factories will be reluctant to adopt labor standards and the default position will be to resist. They will only adopt if they have less power than their buyer; if they are equally powerful, they will not.

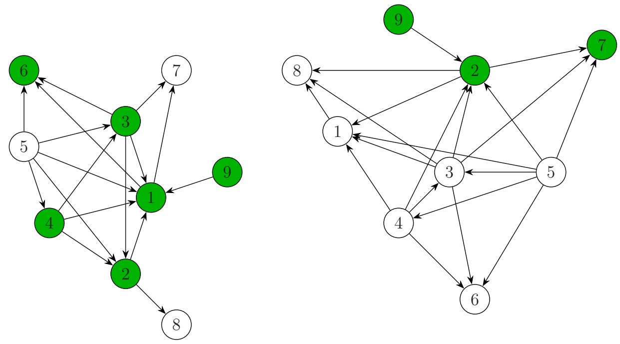

FIGURE 1 Illustration diffusion mechanism with unweighted networks (edge weights are set to be 1). In the panel on the left, Node 6 is the seed trying to force labor standards through its supply chain. In the right panel, the seed is Node 7. The nodes that adopt after several time periods are highlighted

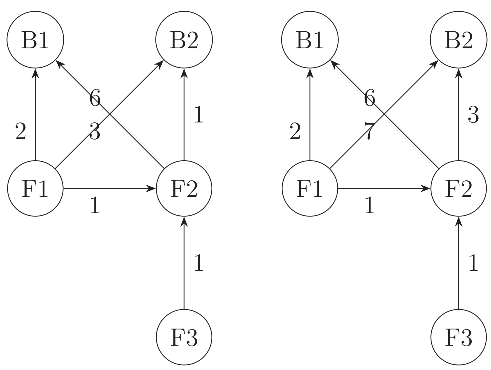

FIGURE 2 Illustration diffusion mechanism with weighted networks. If buyer B1 wants to force labor standards through the supply chain with the weights on the left, all factories will adopt them; however, with the weights on the right, none will. Taking the relationship between buyer B1 and factory F1 as an example, on the left, $V_{ij} = \frac{2}{8} < V_{ji} = \frac{2}{6}$, while, on the right, $V_{ij} = \frac{2}{8} \not< V_{ji} = \frac{2}{10}$

standards if their out-degree is less than three. Applying this rule, node 1 will adopt the standards. In the second time period, the in-neighbors of node 1 will adopt the standards if their out-degree is less than five, so nodes 3, 4, 2, and 9 will now adopt the standards. In the network on the right, node 7 is trying to get its suppliers to adopt the standards; they will if their out-degree is less than three. Node 2, therefore, adopts the standards in the first time period. Node 9 adopts the standards in the second time period. The complexity of this diffusion rises when edge weights are included. This can be seen in Figure 2, where every factory in the left panel will adopt the standards if buyer B1 tries to push them through; however, in the panel on the right, none will.

The implication is that if tier-1 industry weights are similar in size, it is better, in terms of diffusion, for a buyer to have more suppliers. If a buyer must use a dominant supplier and wishes to improve its supply network, it must reduce its reliance on the dominant partner with other suppliers to push through change. For diffusion to occur, the node that is trying to push through labor standards must have two or more suppliers, regardless of the value (edge weight) that each of them supplies. There is no corollary for this; a factory does not need at least two buyers in order to resist having to pay for the implementation of labor standards.

4.3 | Hypotheses testing

To test the proposed hypotheses, power imbalances and dependencies were simulated in the agent-based model and assessed through multiple simulation runs (1,000 times for each industry scenario). We defined the independent variables (i.e., horizontal and vertical complexity and supply network distance, as well as supplier--subcontractor centrality and supplier--subcontractor density) to explain the standard adoption rate of the subsequent linear regression model (see Table 1); therefore, we used the statistics software package R.

$$AR = \alpha_0 + \alpha_1 SSC + \alpha_2 SSDen + \alpha_3 HC + \alpha_4 VC + \alpha_5 SNDist.$$

TABLE 1 Model variables

Variables	Meaning in network science, taken from Newman (2010)	Meaning in the current garment industry context
Adoption rate, *AR*	AR is the dependent variable and the ratio of actual nodes that have adopted the standards, denoted by the number of adopters divided by the total number of network nodes	Whether an actor in the industry has adopted the labor standard
Supplier–subcontractor centrality, *SSC*	SSC is the average number of connections within the supply network denoted by the mean node degree (e.g., if there are 10 nodes, and one node has five connections, this is averaged with the number of connections that the other nine have)	The average number of players each player interacts with. In this context, the number of links can impact positively or negatively on power relationships
Supplier–subcontractor density, *SSDen*	SSDen is the average ratio of actual connections to potential connections in the supply network, denoted by the mean of the ratio of the number of edges to the number of possible edges (e.g., if there are five nodes, they can have four potential connections. When the network realizes two connections, the density can be calculated as 2/4)	This gives an indication of the ratio of actual interaction with other players to the potential interaction
Horizontal complexity, *HC*	HC is assessable through the number of nodes in the supply network	Number of actors in the industry
Vertical complexity, *VC*	VC is assessable through the number of “jumps” in the supply network, denoted by the mean path length between one chosen node and all other nodes (e.g., if there are 10 nodes in the supply network, the average pairs between those 10 and the buyer are taken)	Measure of access that the buyer has to its supply network, equivalent to supply chain tiers. If this is 1 then the buyer knows all the suppliers. A value greater than 1 means there are some factories that are unknown
Supply network distance, *SNDist*	SNDist is assessable by the average path length within the supply network, denoted by the mean of the shortest path length averaged over all pairs of nodes (e.g., if there are 10 nodes, the average pairs between the 10 are taken)	Same as VC, but for all actors or players in the industry, not just the buyer, i.e., agents and other middlemen

4.4 | Scenario analysis

The apparel industry has world-wide exports of over $550 billion to consumer markets around the world (WTO, 2019), featuring broad diversity. To examine the impact of this diversity on our results, we introduced variety into the shape of the supply networks that were tested. To achieve this, we grew networks from a series of scenarios. Starting with a baseline scenario (subcontracting was allowed and there was just one buyer), networks with the required structural characteristics were created as the amount that the single buyer ordered increased (see Table S1-1 in Supporting Information). Accordingly, a scenario analysis was carried out, varying the size of the buyer's orders, as well as the number and size of the large factories. In each scenario, there was sufficient capacity available through subcontracting to an ample number of small factories. In sum, four industry types were examined to test our hypotheses:

Scenario 1 (mass-customized products with higher-quality requirements) featured many large factories and a limited number of buyers, with each buyer placing large orders. Specifically, there were 100 large factories and two buyers; each buyer placed five orders of 200 units. Scenario 1 is illustrated by global (sports/lifestyle) brands, placing large orders for goods that are the same all over the world.

Scenario 2 (simple products with lower-quality requirements) featured many large factories and many buyers, each placing small orders. Specifically, there were 100 large factories and 20 buyers; each buyer placed four orders of 70 units. Scenario 2 suggests large buyers such as supermarkets ordering standard products such as white tee-shirts, which are simpler to produce than the goods in Scenario 1.

Scenario 3 (complex products with high-quality requirements) featured few large factories and few buyers placing large orders. Specifically, there were five large factories and two buyers; each buyer placed five orders of 200 units. Scenario 3 involves more complex products that are usually stocked by larger fashion retailers, for example, clothing that requires a feature such as a brass buckle.

Scenario 4 (small batch production of boutique products) featured few large factories and many buyers placing small orders. Specifically, there were five large factories and 20 buyers; each buyer placed four orders of 70 units. Scenario 4 involves boutique buyers who sell smaller quantities than scenario 3 because of the exclusivity of the product. Due to the small batch size, there are only a few factories willing to take on these types of orders.

The values that we chose to set up and distinguish our four scenarios are meant to be illustrative of the various types of buyers and suppliers. The numbers are not meant to represent single items but should be interpreted as an item being a unit of choice. We used the scenarios purely to create supply networks with variance in their characteristics (see Table 1). The numbers we chose have sufficient variance to create distinguishing

TABLE 2 Synthesized results

Scenario	H1	H2	H3	H4	H5
1	Accepted	Accepted	Rejected	Accepted	Rejected
2	No support	Accepted	Rejected	Accepted	No support
3	No support	Accepted	Rejected	Accepted	Rejected
4	No adoption	No adoption	No adoption	No adoption	No adoption

TABLE 3 Regressing adoption rate on independent variables in industry scenario 1 ($n = 1{,}000$)

Variables	Regression coefficient	Std. error	*t* value	Pr(> |*t*|)
SSC	−66.9134	7.1753	−9.33	0.0000***
SSDen	−85.2688	7.1479	−11.93	0.0000***
HC	0.7685	0.0307	25.06	0.0000***
VC	−12.5152	0.5131	−24.39	0.0000***
SNDist	5.7826	0.9338	6.19	0.0000***

Note: ***, **, * indicate a significance level of 1%, 5%, and 10%, respectively.

scenarios and are at the same time comfortably within the variety that can be found in Bangladesh's garment industry as extracted from WTO (2019). Gray information sources in the industry, such as Segura (2019) and Jones (2017), describe segmentations of clothing brands that are similar to our scenarios.

5 | RESULTS

Adoption of standards took place in industry scenarios 1, 2, and 3; no adoption of standards took place in industry scenario 4, which represents the most homogeneous network. This confirms that standard diffusion is dependent on structural imbalances of power. In line with other agent-based models, we relied on the sign of a coefficient and its size relative to that of the other variables to draw conclusions. Table 2 synthesizes the results with regard to the proposed hypotheses, while the detailed results of the regression analysis for industry scenarios 1, 2, and 3 are presented in Tables 3–5, respectively. Boxplots for each scenario are shown in Figures S1-1–S1-3 in Supporting Information.

TABLE 4 Regressing adoption rate on independent variables in industry scenario 2 ($n = 1{,}000$)

Variables	Regression coefficient	Std. error	*t* value	Pr(> |*t*|)
SSC	−0.4917	2.1092	−0.23	0.8157
SSDen	−21.2711	1.2376	−17.19	0.0000***
HC	0.1461	0.0127	11.52	0.0000***
VC	−2.6690	0.1783	−14.97	0.0000***
SNDist	0.8359	0.5351	1.56	0.1186

Note: ***, **, * indicate a significance level of 1%, 5%, and 10%, respectively.

TABLE 5 Regressing adoption rate on independent variables in industry scenario 3 ($n = 1{,}000$)

Variables	Regression coefficient	Std. error	*t* value	Pr(>|t|)
SSC	−143.4336	97.2187	−1.48	0.1405
SSDen	−623.8607	62.0760	−10.05	0.0000***
HC	0.8768	0.0459	19.10	0.0000***
VC	−46.2532	1.4387	−32.15	0.0000***
SNDist	12.1481	5.1217	2.37	0.0179**

Note: ***, **, * indicate a significance level of 1%, 5%, and 10%, respectively.

According to the results of the linear regression model, supplier--subcontractor centrality consistently had a negative effect on standard adoption in supply networks, although the results were only statistically significant for industry scenario 1. Accordingly, H1 can be accepted for industry scenario 1; this implies that a central position of the supplier–subcontractor network tends to support resistance against labor standard diffusion. In comparison, SSDen had a stronger negative effect on standard adoption in supply networks, with varying effect sizes across industry scenarios, suggesting that H2 can be accepted. In other words, the less densely connected the supplier–subcontractor network, the more the labor standards were likely to spread.

Regarding measures of network complexity, horizontal complexity appears to have a positive (although very small) effect on standard adoption in supplier–subcontractor networks, which means that H3 is rejected. Furthermore, vertical complexity appears to have a negative effect on standard adoption in supplier–subcontractor networks, which means that H4 can be accepted. This negative effect was considerable but still rather small compared to the measures of network asymmetry, namely, supplier--subcontractor centrality and density. In addition, our analysis yielded comparatively small positive effects of supply network distance on the diffusion of labor standards for industry scenarios 1 and 3, whereas no statistically significant effect could be measured for scenario 2. Therefore, H5 could not be confirmed for industry scenario 2 and is rejected for industry scenarios 1 and 3. As a consequence, the more interconnected the supplier and the subcontractors, the harder it was to diffuse standard adoption. With regard to the proposed three complexity measures, our findings suggested that only vertical complexity negatively affects standard adoption in supply networks.

Generally, the observed network asymmetry measures yielded stronger negative effects on standard adoption compared to the proposed network complexity measures. Summarizing the results, a high level of proximity and interconnectedness within the supplier–subcontractor network hampered standard diffusion and shifted the power ratio in favor of the supplier–subcontractor network. Furthermore, it can be seen that an excessive degree of homogeneity prevented diffusion (scenario 4) while strong (power) imbalances supported diffusion (scenario 3) to a certain extent.

6 | DISCUSSION

Our analysis demonstrates that the diffusion of labor standards from buyers throughout supplier–subcontractor networks is complex and contingent on industry structures (see industry scenarios 1–4), even when a simple diffusion rule based on power is applied. As a result, no diffusion of labor standards based on the modeled power mechanisms took place within the industry scenario characterized by a limited number of large first-tier suppliers and a large number of buyers placing small orders. This shows that small- and medium-sized companies do not exert sufficient power to make suppliers adopt labor standards; this reflects insights from survey research by Ayuso et al. (2013), who found that larger businesses are more effective in imposing their sustainability requirements on their business partners. Consequently, small- and medium-sized buying companies either have to rely on other diffusion mechanisms, for example, spreading a common moral vision (Marshall et al., 2019), building commitment through collaboration (Locke et al., 2009), engagement with the suppliers' procurement department (Villena, 2019), forging cooperatives with like-minded peers to demand better working conditions in supplier factories (Mikkelsen & Arlbjoern, 2015), or on direct sourcing that bypasses big factories in order to enforce decent labor standards with smaller suppliers (e.g., Jaffee, Kloppenburg, & Monroy, 2004; Huang et al., 2017). However, in the case of the Indian garment industry, Soundararajan et al. (2018) found evidence that foreign companies typically do not hold sufficient local knowledge to effectively deal with suppliers directly but need sourcing agents as intermediaries to improve poor working conditions in their supply chains.

Considering the level of network asymmetries, the study results point to central and dense network structures among suppliers and subcontractors as opportunities in which to hide suppliers' and subcontractors' bad labor practices; examples include showroom factories dedicated to auditing visits (Labowitz & Baumann-Pauly, 2014; Orsdemir et al., 2019), leading buyers to believe in good labor standards, or making it easy for them to claim ignorance (Caro et al., 2019). In fact, supplier--subcontractor centrality and supplier--subcontractor density represent much stronger obstacles to social standard adoption than network complexity, which has often been blamed for unsustainable upstream suppliers in the literature (e.g., Alsamawi et al., 2014). In line with this, supplier–subcontractor networks that feature high centrality and density take over a "gatekeeping" function and act as pivots for the diffusion of labor standards (Kim et al., 2011).

Almost no research touches upon the phenomenon of hidden or unauthorized subcontracting in supply networks (Caro et al., 2014; LeBaron, 2019), which is the focus of the current study. The principal commonality between multitier supply chains and supplier–subcontractor networks for the purpose of the study is that neither buyer has direct contractual relationships with (all) its manufacturers, thereby restricting the visible horizon of the focal buying firm. Although the perspectives on multitier supply chains and supplier–subcontractor networks overlap, their implications on the visible horizon of the buyer differ (Carter et al., 2015). While the extant literature on multitier supply chain management assumes that first-tier suppliers belong to the visible proportion of the supply base (e.g., Tachizawa & Wong, 2014), the horizontal complexity encountered in first-tier supplier–subcontractor networks in the case of hidden subcontracting confines the visible horizon of the buying firm, and thus precludes direct monitoring and control of subcontractors already at this tier. As suppliers and subcontractors can resist standard diffusion, in particular in central and dense supplier–subcontractor networks, purely power-based diffusion mechanisms are not likely to be effective (cf., Touboulic et al., 2014; Marshall et al., 2019). Summarizing the findings of the present study, the logic of subcontracting may complement and enrich the literature stream on multitier supply chains by adding additional layers of complexity and asymmetries. While we only looked at subcontracting in one supply chain tier, it could easily be the case that subcontracting, that is, the horizontal expansion of supply chain tiers, happens at various tiers or stages, yielding a highly complex picture.

Applying the theory of the nexus supplier (Yan et al., 2015), subcontractors are structurally and relationally embedded in the buyer's supply network beyond direct ties. This means that the buyer has to rely on cascading labor standards via the first-tier supplier (Villena, 2019), thus assigning a double agency role (Wilhelm et al., 2016) to this critical actor in the diffusion process, especially if it holds a central position in the supplier–subcontractor network. This observation may suggest extending the typology proposed by Yan et al. (2015) comprising operational, monopolistic, and informational nexus suppliers to the type of *sustainability nexus supplier* that is critical for cascading sustainability standards through supply networks. Sustainability nexus suppliers may drive diffusion of labor standards through supplier–subcontractor networks, for example, by acting as boundary spanners between buyers and subcontractors that feature high institutional and cultural distance (Soundararajan et al., 2018).

From a methodological angle, agent-based models allow researchers to create situations—in our case, social situations—and repeatedly experiment on them in ways that would be more difficult, expensive, or even impossible in a social science lab. The agent-based model itself becomes a realization of theory, more precise than any description in a spoken language, that can be used to explain the behaviors that emerge (Epstein & Axtell, 1996); in our case, these are decisions about adopting labor standards. Accordingly, agent-based approaches can be used as a methodology for theory development, especially when empirical data collection is difficult, costly, or ethically problematic. If empirical data is available, related findings may be triangulated by findings from model-based research, beyond model calibration and validation; such data and methodological triangulation (Denzin, 1978) may help to build a more comprehensive, precise theory (Jick, 1979).

7 | CONCLUSION

Our agent-based modeling approach for analyzing the impact of network characteristics on the diffusion of labor standards does not come without limitations; these could be addressed by future research. While we investigated this research question for the case of a simple diffusion mechanism based on coercive power, we acknowledge there are other forms of power, such as referent and expert power (Marshall et al., 2019), and that buyer domination (Cox et al., 2001) in supplier–subcontractor networks is not ubiquitous, although it was prevalent in our case of garment sourcing from Bangladesh. Furthermore, we are aware there is an important and diversified body of literature that goes beyond the somewhat simplistic explanation of (social) sustainability diffusion in supply networks through the mere exertion of power. Those studies indicate that collaboration (e.g., Vachon & Klassen, 2006), commitment (Locke et al., 2009), trust (e.g., Peters, Hofstetter, & Hoffmann, 2011), supportive organizational culture (e.g., Carter & Rogers, 2008), sustainability-related capabilities (e.g., Lu, Potter, Sanchez Rodrigues, & Walker, 2018), or business opportunities (e.g., Caro et al., 2019) are drivers for increased sustainability in supply chains. Accordingly, the exclusive application of resource dependence theory reaches its limits and points to complementary theoretical lenses for future research, such as autonomous moral reasoning or sociopsychological norms.

The model further neglects the costs of switching suppliers and adopting labor standards (e.g., paying minimum and living wages) by assuming that all factories realize sufficient profits that allow for such a change in remuneration policy. We therefore omitted the case in which buyers are indirectly responsible for labor rights violations in their supplier–subcontractor networks in that their purchasing patterns exploit "inequalities in the global workplace" (Alsamawi et al., 2014, p. 69), and excessively squeeze suppliers for prices while they simultaneously demand better labor conditions (New, 2015). Accordingly, suppliers may feel pushed into providing low remuneration for shop floor workers or subcontracting to noncompliant factories or household enterprises that use child labor (Gomez-Paredes et al., 2016). Follow-up research may delve into intraorganizational inconsistencies and power struggles of focal buying firms in which Corporate Social Responsibility (CSR) activities create a human facade while purchasing policies exploit vulnerable suppliers (Lund-Thomsen & Lindgreen, 2014; Villena, 2019; Villena & Gioia, 2020). Other avenues of future research could investigate modeling different forms of power exerted on suppliers (Zhao, Huo, Flynn, & Yeung, 2008), and their effects on the behavior of these suppliers toward upstream suppliers or subcontractors (Marshall et al., 2019). Furthermore, the current model could be transferred and adapted to other sectors, such as the electronics industry, where a supply base with ample capacity could be distinguished from a supply base with scarce capacity, particularly when specialized knowledge and advanced technologies are required.

Managers of buying companies that are focal points within their supply chains should be aware that the densely interconnected production capacity of suppliers impedes the diffusion of sustainability standards upstream in supply chains based on coercive power. In those cases, purchasing managers may consider the complimentary use of other forms of power, such as referent and expert power, to create capabilities and a common vision of sustainable work practice throughout the supply chain. The degree of discretion focal buyers have in disseminating labor standards, such as through supplier development and supply chain redesign, comes with the moral obligation of improving the working conditions of vulnerable labor forces in emerging and developing countries (Arnold & Bowie, 2003).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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