Mitigating Sustainability Risk in Supplier Populations: An Agent-Based Simulation Study

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Abstract

Purpose: Many modern firms strive to become sustainable. To this end, they are required to improve not only their own environmental and social performance, but also the performance of their suppliers. Building on population ecology theory, we explore how buyers' exposure to supplier sustainability risk and their subsequent risk management strategies at the buyer-supplier dyad level can lead to adherence to sustainability by the supplier populations.

Design/Methodology: We rely on a bottom-up research design, in which the actions of buyers within buyer-supplier dyads lead to population-wide changes on the supplier side. Specifically, we use experimental data on managing sustainability risk to build an agent-based simulation model and assess the effect of evolutionary processes on the presence of sustainable/unsustainable business practices in the supplier population.

Findings: Our findings suggest that buyers' cumulative actions in managing sustainability risk do not necessarily result in effective population-wide improvements (i.e., at a high rate and to a high degree). For example, in high risk impact conditions, the buyer population is usually able to decrease the population-level risk in a long run, but they would need both power and resources for quickly achieving such improved outcomes. Importantly, this positive change, in most cases, is due to the fact that the buyer population selects out the suppliers with high probability of misconduct (i.e., decreased supplier population density).

Originality/value: Drawing on the organizational population ecology theory, we explore when, to what degree, and how quickly the buyers' cumulative efforts can lead to population-wide changes in the level of supplier sustainability risk, as well as the composition and density of supplier population. Methodologically, this paper is one of the first studies which use a combination of experimental data and agent-based modeling to offer more valuable insights on supply networks.

Keywords: Sustainability Risk, Agent-based Simulation, Population Ecology, Multi-method.

Article Classification: Research paper.

Introduction

The institutional environment that regulates sustainable business practices is changing rapidly as the non-governmental organizations (NGOs) and activist groups increasingly use boycotts, demonstrations, social media, and other tactics to expose sustainability-related issues within supply chains and link them back to the buying firms, hereafter *buyers* (Rugman and Verbeke, 1998, Arenas et al., 2013). The firms are now expected to improve not only their own environmental and social performance, but also the performance of their suppliers. In fact, the supply chain management literature is in agreement that a firm cannot be more sustainable than its supply chain, and any of the firm's suppliers can undermine its efforts to become sustainable. Such a risk associated with a firm's suppliers is referred to as supplier sustainability risk (Roehrich et al., 2014).

Foerstl et al. (2010) define supplier sustainability risk (SSR) as "the risk of corporate reputational damage to the buying firm, caused by supplier [sustainability-related] misconduct[s]" (p. 118). It may occur when salient stakeholders hold a buyer accountable for supplier misconduct related to the natural environment or social communities (Parmigiani et al., 2011, Klassen and Vereecke, 2012, Amaeshi et al., 2008). To avoid any harm to their reputation or economic standing, buyers manage the SSR in various ways that we refer to as *SSR Strategies*, hereafter (Hajmohammad and Vachon, 2016). Their strategic actions at the buyer-supplier dyad level, in turn, are expected to change the behaviour of suppliers at the industry level and, thereby, reshape the composition of the supplier population: some suppliers susceptible to sustainability risk are likely to be selected out of the population, while new organizational forms (e.g., responsible sustainable suppliers) are likely to emerge and grow (Connelly et al., 2011).

In this exploratory study, we apply the *organizational population ecology* (OPE) principles and

assumptions (Hannan and Freeman, 1977) to study the sustainability risk at the supplier population level. Specifically, we explore *if and how (to what degree and at what rate) the dyadic–level SSR Strategies pursued by buyers cumulatively affect the composition and density of supplier population.* By supplier population, we refer to a pool of firms supplying the same products or services at similar price points and quality levels to a group of buyers within a specific industry, which vie for resources (e.g., contracts) in the same competitive domain. The OPE theory provides the appropriate lens for this purpose in two ways. First, it explores the environmental conditions for birth, growth, and longevity of an organizational form over time, which is quite similar to the concept of sustainability implying that a balanced approach toward economic, social, and ecological environment allows the sustainable organizations the benefit of longevity and survival (Wu and Pagell, 2011). Second, it describes and explains the organizational change phenomenon at the population or macro level.

To address the above-mentioned research questions, we use dyad-level experimental data on SSR Strategies to build an agent-based simulation and assess the effect of evolutionary processes on the presence of sustainable and unsustainable business practices at the supplier population level. It is noteworthy that we do not seek to identify the optimal buyer behaviors in buyer-supplier dyads; rather, we rely on the documented empirical data and build an agent-based simulation that incorporates actual decisions made by buyers at the dyad level to understand their cumulative effects at the population level. We choose to employ agent-based simulation due to its ability to capture the complex dynamics of modern supply chains and probabilistic nature of SSR (Hearnshaw and Wilson, 2013).

This study offers a number of theoretical and methodological contributions. First, we contribute to the emerging literature on network-level SSR management (Busse et al., 2016, Busse et al.,

2017, Touboulic et al., 2014, Canzaniello et al., 2017) by exploring when, to what degree, and how quickly the cumulative efforts of buyers can lead to population-wide changes in the level of SSR, as well as the composition and density of supplier population. The results demonstrate how various actions of a buyer population change the characteristics of the supplier population. Specifically, we show that powerful and resourceful buyers can eliminate SSR from their supplier population by having a cumulative positive effect on suppliers' performance, while other buyers achieve lower SSR exposure by sourcing from a small number of low-risk suppliers.

We also contribute to the literature on organizational population ecology theory by applying it to the new context of buyer-supplier populations and providing empirical support for the density dependence model (Hannan and Carroll, 1992). Finally, we contribute to the supply chain management literature from a methodological standpoint by combining dyad-level experimental data and agent-based modelling to offer more valuable insights on the phenomenon under study at the population level that would not have been possible by relying on a single method (Turner et al., 2017).

In the following sections, we first describe the notion of supplier sustainability risk, followed by an introduction of the organizational population ecology theory and how it has been applied in this study. After presenting the details of the agent-based simulation methodology and data analysis, the simulation results are presented and discussed alongside our theoretical, methodological, and managerial implications.

Managing SSR at the Buyer-Supplier Dyad Level

SSR Strategies

Supplier sustainability risk refers to the likelihood and consequences of a sustainability-related

misconduct occurring in the buyer's supply chain and being detected by concerned stakeholders (Roehrich et al., 2014). Managing SSR is imperative to buyers' competitiveness and long-term success (Eccles et al., 2007, Busse, 2016) and, as with any other type of risk, their risk management strategy may fall under three categories: risk avoidance, risk mitigation, or risk acceptance (Ritchie and Brindley, 2007, Blome and Schoenherr, 2011, Lemke and Petersen, 2013). Although organizations may try to manage the risk at the corporate level through interactions with multiple stakeholders – such as NGOs, governmental authorities, competitors, and consumers (Busse et al., 2017, Wright, 2016) – our study focuses on the operational-level actions that affect the interactions between a buyer and its suppliers (Pagell and Gobeli, 2009). In their conceptual paper on managing SSR, Hajmohammad and Vachon (2016) suggest that such strategies include *supplier phase-out*, *sustainable supplier development*, or *taking no action*.

By implementing supplier phase-out strategy, the buyer terminates the relationship with the incumbent risky supplier and switches to an alternative supplier with a clean sustainability record to ultimately avoid the risk. Sustainable supplier development strategy, on the other hand, fits into the risk mitigation category (Ritchie and Brindley, 2007). It is defined as the buyer's plans to integrate the ecological and social issues into supply management process to improve the supplier performance on those dimensions (Krause et al., 2007, Klassen and Vereecke, 2012). By doing so, the buyer gets to reduce the probability of SSR by enhancing suppliers' environmental and social performance through direct interaction with them and implementation of jointly-developed programs and initiatives (Golicic and Smith, 2013), such as training the suppliers, compensating them for the costs associated with their compliance (e.g., joint investments in environmental friendly equipment), or sponsoring ecological or social summits for suppliers to encourage the sharing of information and experience (Vereecke and Muylle, 2006). Finally, by deliberately

taking no action, the buyers simply accept and retain the risk and suffice to plan for dealing with the consequences of the potential risk should it happen at some point in the future (Sodhi and Tang, 2012).

Predictors of SSR Strategies

Based on resource dependence (Pfeffer and Salancik, 2003) and agency theories (Eisenhardt, 1989), Hajmohammad and Vachon (2016) suggest that two major factors can influence buyers' choice of SSR Strategy: level of their *perceived SSR impact*, as well as level of *supplier dependence* on the buyer.

Buyer's perceived risk impact- A number of conceptual and empirical studies have suggested and confirmed that the effect of various contextual factors on the managerial decisions is mainly mediated through the decision makers' risk perception (Kocabasoglu et al., 2007, Sitkin and Weingart, 1995, Ellis et al., 2010). Risk perception is generally defined as the decision-maker's assessment of the risk inherent in a situation (Sitkin and Weingart, 1995). A number of studies suggest that one of the prevalent drivers of the firms' decision to adopt sustainable supply chain management initiatives is their managers' perception of the risks involved (Zhu and Sarkis, 2007, Walker and Jones, 2012). Hence, it is plausible to assume that the buyers' strategic decisions in the context of our study is also well influenced by their subjective assessments of the SSR impact (i.e., perceived risk impact) inherent in their relationship with a specific supplier.

Buyer's power- By definition, an organization is dependent on another if the latter controls important resources and the former relies on it for access to those resources (Pfeffer and Salancik, 2003). Given this, one party's dependence on another enables the dominant partner to exert greater influence over the weaker partner (Casciaro and Piskorski, 2005, Gulati and Sytch, 2007). Particularly, supplier dependence on buyer increases the buyer's relative power in the relationship

and enables them to significantly influence the actions and intentions of the supplier (Benton and Maloni, 2005, Bastl et al., 2013, Lanier et al., 2010): the dependent suppliers are more likely to cooperate with the buyers (Modi and Mabert, 2007, Takeishi, 2001) and to make changes to their production processes and product specifications to meet the buyers' requirements (Hallen et al., 1991). For example, Carr et al. (2008) show that the increased supplier dependence increases supplier involvement in buyer's product development and supported training. In the same vein, in a buyer-supplier dyad, the buyer's SSR Strategy would depend on the level of its power over the supplier.

Buyer's resource scarcity- In addition to the two identified predictors mentioned above, buyers also need to have a sizeable level of excess resources to pursue proactive strategies (Singh, 1986). A buyer that has organizational slack ─ the cushion of actual or potential resources which are not consumed by the necessity of the continued daily operations of the firm ─ can successfully adapt to the internal or external pressures and initiate changes in strategy with respect to the external environment (Bourgeois, 1981, Voss et al., 2008). Specifically, financial slack allows the buyers to invest in initiatives with positive performance implications, such as SSR Strategies, that do not have an immediate pay-off and require a longer investment horizon (George, 2005). In other words, the type of SSR Strategy buyers can pursue is well limited by the slack resources at their disposal (Latham and Braun, 2009).

Therefore, we consider the buyers' resource scarcity as another major predictor of their SSR Strategy. This argument is reinforced by a number of studies showing that availability of slack resources drives managerial choices in favor of sustainability-related issues, such as the scope and scale of environmental-friendly initiatives (Bansal, 2003), socially responsible funds (Peillex and Ureche-Rangau, 2016), and social engagement and corporate social responsibility expenditures

(Seifert et al., 2004, Surroca et al., 2010). Particularly, Cousins et al. (2004) propose that the stock of resources available to the purchasing functions is a crucial enabler of their environment-related supplier management initiatives. Based on their framework, a low resource scarcity is associated with performing basic supplier development initiatives and forming collaborative relationships with suppliers to improve their performance. However, high resource scarcity makes the purchasing functions to either take a "why bother" strategy and suffice to comply with relevant laws and regulations or, at most, to do simple supplier monitoring activities.

Organizational Population Ecology Theory

Organizational population ecology theory (Hannan and Freeman, 1977) ─ particularly, its density dependence model (Hannan and Carroll, 1992) ─ is the most prominent paradigm that can account for the changes in the composition of the organizations at a population level. Particularly, the population ecologists attempt to explain the emergence, growth, and demise of organizational forms in response to their institutional environment (e.g., social, economic, and political) over time (Dobrev et al., 2006, Bogaert et al., 2016). A population is defined as a collection of organizations which are similarly dependent on the environment, rely on certain common resources, and have limited range of activities and structures. Organizational form is an abstract representation of a population of organizations "that are alike in some respect" (p. 934) and "have a common form" (p. 936) (Hannan and Freeman, 1977).

The OPE theory initially challenged the prominent view that individual organizations and their decision makers learn and internally adapt to changes in the environment without consequence, aka the adaptation view (Pfeffer and Salancik, 2003, Lawrence and Lorsch, 1967). Alternatively, it put forth the selection view suggesting that organizational forms change at the population level, and their evolution and survival is driven by the institutional environment selection processes (van

Witteloostuijn, 2000). Since the environment changes more rapidly, it has a selection advantage over the relatively inert organizations (Bogaert et al., 2016). More specifically, the population's composition changes through the processes of variation, selection, retention, and competition: the organizations tolerating the environment's pressures survive or are "selected into" the population by the environment and the rest are "selected out" (Baum and Shipilov, 2006).

The density dependence model holds that the growth and mortality rates of organizations in a population are a function of the number of similar operating organizations at any given point in time and within the same population (Hannan and Carroll, 1992). As the number of organizations with characteristics congruent with prevailing institutional norms (i.e., population density) increases, the environment perceives them as a natural and acceptable organizational form and stimulates their growth. This positive density effect, however, has a saturation point. When the population contains a large number of these organizations (high population density), appearance of similar organizations does not improve the environment's perception of these organizations any further. On the contrary, scarcity of available resources gives rise to more intense competition within the population so that, after the saturation point, the population density may remain the same or even decrease (Bogaert et al., 2016).

In this research, we employ the OPE theory in the context of SSR management. The pool of suppliers of a component, material, or service in a specific industry with similar price points and quality levels, which vie for resources (e.g., contracts) in the same competitive domain, can be regarded as a population that strives for survival in the global market. In addition, the population of the buyers sourcing from these suppliers can be considered as the major environmental element whose selection processes may significantly affect the characteristics of the supplier population. We employ the cumulative behavior of the buyers (i.e., the environment) in managing SSR to

study the changes in characteristics of the supplier population and its density. More specifically, we focus on the situations where a population contains high-risk suppliers, i.e., suppliers that are very likely to expose buyers to sustainability risk. We, then, explore how a collection of buyers' dyadic SSR Strategies can gradually affect the survival rate of suppliers and the level of SSR within the supplier population. In doing so, we focus on both the degree and the rate of the change effects of buyers' cumulative actions.

Methodology

The aim of this study is to investigate how the decisions of buyers about managing SSR shape the characteristics of the supplier population, i.e. a set of suppliers that produce the same inputs at the same price and quality level. We leverage the advantage of simulation methodology to study temporal effects. Specifically, we seek to understand (i) whether buyers' decisions at the dyad level would influence the size of the active supplier population over time, and (ii) how the supplier population propensity to expose buyers to sustainability risk would change over time. Rather than seeking to identify optimal buyer behavior in a buyer-supplier dyad, our model incorporates actual and empirically-observed decisions made by buyers at the dyad level, collected through a vignette-based experiment.

Simulation is a theory-building methodology often used to study emergent research topics (Davis et al., 2007). We employ agent-based simulation as the research method in this study (Wilensky and Rand, 2015), which is widely-used when the phenomenon under study involves a "collection of autonomous decision-making entities, agents" (Bonabeau, 2002), such as buyers and suppliers. Past research has applied agent-based simulations to study diverse management topics such as teamwork and innovation diffusion (Crowder et al., 2012, Rahmandad and Sterman, 2008) as well as temporal changes in populations (Tobias and Hofmann, 2004, Mathevet et al., 2003,

Christensen and Sasaki, 2008). This type of simulation allows for valid representation of complex and dynamic phenomena as it can mimic the uncertain behaviors of agents who interact with one another and with the system they comprise (Bonabeau, 2002, Fioretti, 2013).

Hearnshaw and Wilson (2013) recommend agent-based simulation as a method for modelling buyer-supplier systems and recent studies have used it to study complex supply chain phenomena (Tong et al., 2018, Pan and Choi, 2016). This simulation method is a bottom-up approach used (i) where agent behavior is modelled to understand the dynamics of an entire system (e.g., a population of buyers sourcing from a population of suppliers) (Macal and North, 2010), and (ii) where agents (e.g., buyers and suppliers) exhibit uncertain behavior, possess heterogeneous characteristics, and their interactions influence their actions (Bonabeau, 2002). Specifically, the agent-based simulation can capture the complex dynamics of modern supply chains and probabilistic nature of sustainability risks.

While approaches of combining different methods are still developing (Hesse-Biber, 2010), a popular approach is to use the results of one method as an input for the second method (Molina-Azorin, 2012, Tong et al., 2018). As Midgley et al. (2007) point out, empirically grounded simulations tend to be "realistic, at least to some degree of face validity, and … evidently complex in overall structure". Following their recommendation and to ensure our model's validity, we use empirical data on SSR management in buyer-supplier dyads to ground the simulation assumptions. Using buyer-supplier dyadic data allows us leverage the bottom-up nature of the agent-based simulation to study a system where the behavior of agents comprising it is specified.

Empirical Data

The empirical data in this study was collected for the purpose of a vignette-based experiment conducted in 2014-2015 using a sample of 200 full-time supply managers working for medium or

large companies in the Unites States. Vignette-based experiment has a long tradition in decision sciences and proved to be useful for the study of major strategic decisions (Bazerman and Moore, 2008). This is particularly true because the causal relationships between decision's predictors and outcomes are investigated under controlled conditions (Croson et al., 2007, Tjemkes and Furrer, 2010). By controlling for the confounding effects, experiments rule out the variety of contextual factors which influence the managerial behavior (Bateman and Zeithaml, 1989) and eliminate the endogeneity concerns by isolating the causality (Echambadi et al., 2006).

This methodology is being increasingly used by operations and supply chain management scholars to address their diverse research questions (Bazerman and Moore, 2008, Ball et al., 2018, Mir et al., 2017, Azadegan et al., 2019). Vignettes are short scenarios presenting a case/situation to participants who are then asked to describe their possible actions given a series of pre-set circumstances (Alexander and Becker, 1978). Although the vignette-based experiment looks like a survey, it contains all the components of an experimental design (i.e., random assignment to the cells, manipulated independent variables, and measured dependent variables) and thus can be shown to eliminate the possibility of systematic differences in the participants or the environment that could affect the outcomes (Creswell, 2013). Therefore, the observed differences noted can be attributed to the experimental manipulations, thus allowing a step beyond correlation tests to actual tests of causality (Siemsen, 2011). It also reduces the biases from memory lapses, rationalization tendencies, and consistency factors (Grewal et al., 2008). In addition, there is evidence that when given information about a hypothetical situation (e.g., a scenario), people properly anticipate the situation that is similar to what actual participants would do (Angrist and Pischke, 2008).

The experiment in this study focused on a buyer-supplier dyad (Thomas et al., 2013, Tangpong et al., 2010) and examined the factors affecting the supply managers' strategic choices for

managing SSR including (1) the risk impact, i.e., whether the occurred supplier misconduct may lead to a buyer experiencing significant reputational and financial losses, (2) buyer's power, i.e., whether a buyer can influence the supplier's behavior, and (3) buyer's resource scarcity, i.e., whether a buyer has resources available to properly manage the risk. The scenarios were developed to present fictitious mid-sized multinational companies in the apparel retail and the food industries, which had recently extended their safety or environmental policies to include suppliers' operations. Each scenario also featured a supplier company with a record of environmental or safety misconduct(s). Neither scenario used a recognizable brand name to reduce potential biases related to particular companies.

Eight vignettes for each scenario were carefully designed to allow the manipulation of all three treatment factors at two levels. To manipulate the degree of risk impact, the respondents in the low risk impact vignette dealt with a supplier which had received one violation citation from the local government authorities because of a sustainability-related misconduct. Conversely, in the high risk impact vignette, they were faced with a supplier which was targeted by a reputable international activist group and highlighted on their website because of sustainability-related misconduct. Inspired by Lanier et al.'s (2010), the buyer's power was manipulated by describing in the scenario a supplier whose sales significantly depended on the buyer (high buyer power) versus a supplier which allocated small portion of sales to the buyer (low buyer power). Lastly, the participants assigned to the low resource scarcity vignette were informed that the CEO had allocated a special annual budget to their department for making the necessary changes to supplier management activities, whereas those assigned to the high resource scarcity vignette were informed that the CEO had asked them to make the necessary changes to supplier management activities within their department's current budget limits.

The participants were asked to assume the role of Procurement and Supply Management Director and — given the situation outlined in the vignette — decide how their company should intervene. In particular, they were asked whether they would develop the supplier capabilities (or not), phase-out the supplier (or not), or accept the risk and take no actions. The first two actions are oriented toward decreasing the probability of experiencing future supplier misconduct. The values for the odds of these decisions were calculated using the binomial logistics regression equations that included the three parameters outlined above and their two-way as well as three-way interactions (Table 1). The odds value of a decision represents the likelihood that the decision would be made against the likelihood that it would not be made. The details of the experimental design and its results are available upon request.

--- Insert Table 1 here ---

Agent-Based Simulation

Using the abovementioned experimental data on decisions made by the buyers within their buyer-supplier dyads, we built an agent-based simulation in NetLogo to explore how these decisions affect characteristics of the supplier population over time. The details of simulation are described in this section and its flowchart is presented in Appendix I. The simulation starts at $\mathrm{t} = 0$ with a population of N buyers-supplier dyads. We set N at 20 buyer-supplier dyads and demonstrate the robustness of the results relative to the starting values of N in Appendix II. Following the structure of the experimental data, each of the N buyers procures from a single supplier. Drawing from the OPE theory, we seek to observe the emergence of suppliers with low sustainability risk. As a result, at $\mathrm{t} = 0$, the supplier population contains only suppliers with high probability of misconduct P_{MC} which is set at 0.70. We demonstrate the robustness of the results relative to the starting values of P_{MC} in Appendix II.

At each subsequent period $t = 1,2,3 \ldots$, in each dyad, a buyer procures an order from its supplier. At every time period, the buyer faces the probability of supplier misconduct, i.e. the supplier's failure to avoid damage to natural environment or social communities. If a buyer learns about the misconduct, it can take actions towards reducing the probability P_{MC} of supplier misconduct that it faces. We take into account that a buyer may not be aware of all occurrences of supplier misconduct and, therefore, introduce a measure of visibility in the simulation. Drawing from the previous research (Christopher and Lee, 2004, Tse and Tan, 2012), we refer to the visibility as the buyer's ability to gain information of an occurred supplier misconduct. We, thus, operationalize visibility P_V as the probability of learning about the occurred supplier misconduct. We set P_V at 0.50 and demonstrate the robustness of the results relative to the starting values of P_V in Appendix II.

If a buyer becomes aware of its supplier misconduct, it then makes decisions regarding the supplier responsible for the misconduct. These decisions are driven by the empirical data collected in the experiment and depend on the degree of risk impact I:I$\in\{0,1\}$, the buyer's power P:P$\in\{0,1\}$, and its resource scarcity R:R$\in\{0,1\}$. In the simulation, we ran eight scenarios to consider all possible combinations of binary values of these three parameters as outlined in Table 2. These parameters, in turn, determine whether the buyer would decide to attempt to develop the supplier capabilities, phase-out this supplier, or do nothing. Values used for the simulation parameters are summarized in Table 3. Each scenario was run fifty times and the results reported are based on average values for each scenario.

--- Insert Tables 2 and 3 here ---

Experimental data shapes the odds with which the buyer decides to develop supplier capabilities. In the simulation, if the buyer makes this decision, the simulation algorithm then

decreases the probability of supplier misconduct by a random value. Simultaneously, experimental data shapes the odds of not taking this action. In case a buyer decides not to develop supplier capabilities, it next considers whether it should phase-out this supplier, a decision similarly driven by the experimental data. If the firm decides to phase-out the supplier, it then switches to another supplier. A decision to phase-out the supplier necessitates the buyer to find an alternative supplier. In the simulation, the buyer then switches to a supplier that is currently supplying to another buyer and has not committed any misconduct at this time period. If the buyer decides to neither develop supplier capabilities nor phase out the supplier, the simulation then assumes that the buyer decided to do nothing about the supplier misconduct and continue sourcing from the same supplier despite the occurred misconduct.

At each time period, these decisions are made by all buyers in the simulation that become aware of supplier misconduct. All other buyers that either have not experienced a supplier misconduct or not become aware of an occurred misconduct continue sourcing from their current supplier. The simulation runs for $i = 60$ time periods. In Appendix II, we demonstrate the robustness of the results relative to the starting values of i.

The combined actions of all buyers within the simulation network then shape the population of the suppliers and affect the presence of SSR in the supplier population. At each time period, the simulation tracks three outcomes. The first outcome, the proportion of active suppliers, refers to the proportion of suppliers working with at least one buyer. This outcome tracks the proportion of suppliers that are used by buyers in the simulation. The simulation starts with N buyer-supplier dyads. Therefore, initially all N suppliers are active, i.e. each of them has a buyer. If a buyer, however, experiences supplier misconduct, it can switch to another supplier and, gradually, some suppliers may end up without buyers. This outcome, therefore, tracks how the supplier population

density changes over time. Two other outcomes capture the extent to which buyers' actions were effective at reducing occurrence of supplier misconduct in the supplier population. Specifically, the simulation tracks the average and maximal probabilities of misconduct among active suppliers. These outcomes correspondingly track the improvement of the SSR level on average and for the worst supplier remaining in the population.

After we implemented the simulation algorithm, we verified whether the conceptual model was correctly represented in the programming code (Rand and Rust, 2011; Wilensky and Rand, 2015). First, we separately tested each sub-section of the code. Second, a researcher who did not participate in coding checked the programming code for accuracy. Third, we checked corner cases for the probability of supplier misconduct P_{MC} and the probability of learning P_V by setting these values to zero. As expected, the characteristics of supplier population does not change if either of these values are zero. Finally, sensitivity analysis of the code reported in Appendix II shows that the simulation results are robust to changes in the simulation inputs.

Results

In this study, we seek to understand how the pressure from buyers to eliminate SSR shapes the supplier population over time. In Table 4, we provide the results of the simulation for eight considered scenarios. These outcomes are based on parameters reported in Table 3. Figures 1, 2, and 3 report the results graphically, and show how the values of the three outcome variables change with time. The simulation's ability to track temporal changes allows us better analyze both the degree of change and the rate of change over time and compare them across eight scenarios.

--- Insert Table 4 here ---

Figures 1 and 2 show that various buyer populations can decrease their exposure to SSR, but they vary greatly by the degree and rate of their change effect. Figure 1 tracks the average

probability of supplier misconduct among active suppliers, i.e., suppliers that work with at least one buyer at that time period. For all eight considered scenarios, the average probability decreases at a decreasing rate, saturating after a certain point. Interestingly, the improvement is observed even for scenarios where each particular buyer's decision to develop a supplier is unlikely. And yet, due to cumulative efforts of buyers, supplier population is significantly improved in terms of average probability of misconduct. The eight scenarios, however, differ in the rate at which the buyers are able to reduce the average probability of misconduct (i.e., change effect rate) and to what level (i.e., change effect degree). When buyer population faces a low risk impact (Figure 1, Panels A and B), both power and resources are required for buyers to push the supplier population's average probability of misconduct at a fast rate to the lowest level. In three other scenarios with low risk impact, the process of diminishing the average probability is slower and converges at a higher probability value. In other words, when buyers face low risk impact, having both power and resources is necessary for them to drive down the average probability of misconduct in supplier population. In contrast, facing a high risk impact seems to be a sufficient condition for reducing the average probability of misconduct (Figure 1, Panels C and D): in four scenarios with high risk impacts, buyers are able to swiftly reduce the average probability of misconduct regardless of the power and resources they have.

Proposition 1. When a buyer population faces low risk impact, they reduce the average probability of misconduct in the supplier population to a high degree and at a high rate, only if they have both power and resources.

Proposition 2. When a buyer population faces high risk impact, they reduce the average probability of misconduct in the supplier population to a high degree and at a high rate, regardless of their power and resources.

--- Insert Figure 1 here ---

The results for maximal probability of misconduct displayed in Figure 2 track the presence of high-risk suppliers in supplier populations that, on average, are not likely to commit misconduct. These results reveal a number of surprising findings. First, when buyer population faces a low risk impact (Figure 2, Panels A and B), their efforts are effective at removing high-risk suppliers from the population only when they have high levels of power and resources. However, suppliers with a high misconduct propensity remain in the population in all three other scenarios for low risk impact. In other words, in industries where buyers face low risk impact, one should expect to see the elimination of sustainability risks only if the buyer population has high levels of both power and resources. In all other situations for low risk impact, buyers may achieve lower probability of misconduct on average, but some of them may still source from suppliers with significant sustainability risks. Second, when the buyer population faces a high-risk impact (Figure 2, Panels C and D), they are more effective at eliminating suppliers with high probability of misconduct from supplier population, regardless of their power and resources. Yet, the results are more nuanced that those for the average probability of misconduct. Specifically, buyer population needs to have power and resources to assure a high rate of change in the maximal probability of misconduct. These results reveal that facing high risk impact will allow buyers eliminate suppliers with high probability of misconduct from supplier population but only with buyers' power and resources can this change occur rapidly.

Proposition 3. When a buyer population faces a low risk impact, they reduce the maximal probability of misconduct in the supplier population to a high degree and at a high rate, only if they have both power and resources.

Proposition 4a. When a buyer population faces a high risk impact, they reduce the maximal probability of misconduct in the supplier population to a high degree, regardless of their power and resources.

Proposition 4b. When a buyer population faces a high risk impact, they reduce the maximal probability of misconduct in the supplier population at a high rate, only if they have both power

and resources

--- Insert Figure 2 here ---

While the above results focus on the changes in probability of misconduct, the results displayed in Figure 3 focus on the effects of buyers' decisions on the density of supplier population. When buyers lack power, the supplier population shrinks over time regardless of the risk impact they face and resources they have. In other words, without power, buyers gravitate to and then source from a niche of suppliers that are on average not prone to causing supplier misconduct. In contrast, buyers with power choose to keep a higher number of suppliers in the population. The largest supplier population among eight scenarios is when buyers have power and resources and face high risk impact. As Figures 1 and 2 demonstrated, such buyer population is capable of eliminating the misconduct probability of almost the whole supplier population. As a result, this buyer population retains the vast majority of suppliers in the population.

Proposition 5. The supplier population density shrinks significantly more when they face a buyer population that lacks power rather than a powerful buyer population, regardless of the risk impact and the buyer population resources.

Proposition 6a. The supplier population density shrinks similarly whether they face a buyer population with high or low source scarcity, unless the buyer population is powerful and faces a high risk impact.

Proposition 6b. The supplier population density does not shrink significantly when a powerful and resourceful buyer population faces a high risk impact.

--- Insert Figure 3 here ---

Discussion

Theoretical and Methodological Contributions

To effectively manage the supplier sustainability risk, buyers must overcome challenges that are internal to their supply chains, such as the lack of supply chain visibility, and cope with external

problems, such as contradictory and inconsistent pressures from varying cultural traditions, normative values, and regulative standards (Busse et al., 2016, Busse et al., 2017). Some recent studies have attempted to explore SSR strategies within supply chain networks rather than buyer-supplier dyads (Touboulic et al., 2014), as well as strategies involving parties not directly connected to the chain. For example, Canzaniello, Hartmann, & Fifka (2017) suggest that buyers can benefit from sharing the risk, costs, and benefits if they form intra-industry strategic alliances aiming at establishing common sustainability-related SCM endeavours and approaches. Similar intrafirm initiatives exist in some industries. For example, the "Roundtable on Sustainable Palm Oil" is a private governance initiative to develop an internationally-recognized standard to improve sustainability of the global palm oil commodity chain (Schouten and Glasbergen, 2011). However, the majority of existing studies in the literature on managing SSR or diffusion of sustainable practices across supply chains view these phenomena from a static perspective by focusing on individual firms or buyer-supplier dyads and fail to address temporal effects caused by the dynamics of environments in which multiple agents interact with one another, such as buyer and supplier populations (Klassen and Vereecke, 2012, Amaeshi et al., 2008, Aguinis and Glavas, 2012, Shafiq et al., 2017).

As such, our study contributes to sustainable supply chain management and supply chain risk management literatures by adopting a multi-agent system approach and focusing on a system of multiple buyers and suppliers. Specifically, we explore how this system evolves as a result of individual buyers' choices among SSR strategies, and investigate (i) when (i.e., under what conditions), (ii) to what degree, and (iii) at what rate the cumulative effects of a buyer population efforts can lead to changes in the level of SSR and the composition and density of a supplier population.

Our results reveal that in all considered scenarios, regardless of buyers' characteristics and the risk impact they face, one should expect improvement in the average SSR in a supplier population over time. These improvements reflect the cumulative effects of buyers' efforts. Even for scenarios in which each particular buyer is unlikely to commit to supplier development, occasional decisions by some buyers to develop supplier capabilities will eventually create a situation where buyers source from a sub-population of suppliers which, on average, tend not to commit sustainability-related misconduct. Simultaneously, our results show that such improvements in the average SSR are not always mirrored by similar improvements in the maximal SSR in the supplier population. These contrasting findings have an important implication for supply chain sustainability research. Existing research often singles out cases of severe supplier misconduct, such as 2013 Rana Plaza collapse, to demonstrate the importance of assuring supply chain-wide adherence to sustainability (Croom et al., 2018, Kim et al., 2019). While we do not dispute the value and validity of these arguments in any way, our results point out the importance of distinguishing the average risk inherent in a supplier population from the worst performing suppliers in that population. As our results reveal, one can simultaneously find evidence of suppliers' commitment to sustainability (Blome et al., 2014, Mani et al., 2018) and a continuous presence of a limited number of high-risk suppliers in a supplier population.

Furthermore, while our findings are in line with the previous research that highlights the importance of increasing stakeholder pressure on buying firms (Parmigiani et al., 2011, Meixell and Luoma, 2015, Foerstl et al., 2010), we provide a more nuanced picture of the critical role strong stakeholder pressure plays in supply chain sustainability. Our findings suggest that buyers that face low risk impact can improve the SSR level in their supplier population, and yet we found that being exposed to a high risk impact down-weighs the role of other factors, such as buyers'

power and their resources, in reducing SSR in a supplier population. In fact, the results show that one should expect significant changes both in average and maximal SSR present in a supplier population if the risk impact is high, regardless of the buyers' power and resources. Although, without both power and resources, the maximal SSR reduces at a slower rate as the buyers gradually phase out the suppliers with high probability of misconduct (i.e., decreased density of supplier population); the remaining supplier population would include the ones with lower probability of misconduct. This result has an important policy implication. When external stakeholders (e.g., NGOs, governmental agencies, and general public) threaten buyers with severe repercussions for their suppliers' misconduct, these buyers may require considerable time to eliminate high-risk suppliers from their supplier population if they lack either internal resources or power over their suppliers. Furthermore, when buyers are pressured to make significant improvements in their supply chains (i.e., face high-risk impact), it is assumed that they are capable of making such a transition. However, our results suggest that pressuring buyers may not be sufficient to assure population-wide improvements on the supplier side. Instead, when buyers lack either power or resources, they demonstrate a tendency to switch to procuring from a small number of suppliers rather than creating population-wide changes. In other words, sustainability may become a niche with many suppliers being simply removed from the population because they are prone to committing sustainability-related misconduct. When targeted by stakeholder threats, only buyers with both power and resources can assure population-wide improvements in SSR level among suppliers.

Interestingly, even when buyers do not face severe repercussions from the misconduct of their suppliers (i.e., face low-risk impact), they can still improve both average and maximal SSR levels in supplier population if they possess both power over their suppliers and internal resources.

Otherwise, although they may achieve lower average SSR, some of them are still expected to procure from suppliers with significantly high SSR level. While prior research on sustainability has questioned the ability of large powerful firms in making radical changes to their supply chain sustainability (Shevchenko et al., 2016, Girotra and Netessine, 2013, Schaltegger and Wagner, 2011), our results confirm that the power these firms have over their suppliers and the internal resources they possess can play a crucial role in making it happen (Meqdadi et al., 2018, Touboulic et al., 2014).

We further contribute to the literature on organizational population ecology theory by applying it to the new context of buyer-supplier populations and providing empirical support for the density dependence model (Hannan and Carroll, 1992). Particularly, as mentioned above, our results demonstrated that the composition and density of supplier population significantly changes over time in response to the buyer population (parallel to OPE's institutional environment) and their strategic actions in managing SSR (parallel to OPE's selection processes). At the beginning, the supplier population density as well as the average probability of misconduct, drop rather quickly in response to buyers' phase-out strategy toward suppliers with high probability of misconduct. This can be interpreted as emergence and growth of a new organizational form (i.e., sustainable suppliers) within the supplier population. Gradually, with the increase in buyers' development efforts which require more resources on their part, this trend slows down and the density of supplier population with low probability of misconduct remains constant at a certain level.

This paper also offers a number of methodological contributions. First, as Hearnshaw and Wilson (2013) argue, the agent-based modelling methodology has the potential to offer realistic models of supply chain systems because it incorporates the interactions among various involved members. We demonstrated how this simulation technique can be employed in the area of supply

chain sustainability to enhance our understanding of the SSR management at the population level, an understudied and less explored level of analysis that is hard to tackle using empirical methods only. Second, we enhance the validity of the results by building the simulation based on the empirical data for actual decisions made by managers rather than hypothetical and artificial data. Third, despite the lack of guidelines for combining analytical and empirical methods in our field (Hesse-Biber, 2010), researchers have been encouraged to take this approach to offer more valuable insights that may not be possible by relying on a single method (Turner et al., 2017). Besides, more multi-level research studies are required to extend the boundaries of existing knowledge about sustainable operations and supply chains (Aguinis and Glavas, 2012). Our study puts forth one of the first successful examples in this line of research and contributes to both theory and practice by using a multi-method approach to extend the level of analysis; particularly, we used the results of an experimental study of the SSR management phenomenon at the buyer-supplier dyad level to build an agent-based simulation model and explore the same phenomenon at the population level.

Managerial Implications

This study provides valuable managerial insights to all the stakeholders who play a critical role in reducing the supplier sustainability risk. First, the results show that only when sustainability-related misconduct are considered as severe (i.e., a high-risk impact) throughout the industry – and not by a small number of members – a meaningful population-wide change can be instilled. That is why environmental and social activist groups and NGOs may not perform effectively by single-targeting a few brand names and reputable companies; however, their efforts should be coupled with population-wide regulations and legislations to create risk awareness and call for action by all the industry members.

Second, since both power and resources are essential for effective elimination (rather than mitigation) of the SSR, companies are better off if they join forces, as well as resources, and act in a united way through population-wide collective actions with regard to their suppliers. Finally, suppliers should be aware that their survival in this changing environment depends on their proactivity in gradually adopting environmental- and social-friendly practices because it will not be long before they lose their position in the market once their buyer population starts considering their misconduct as some sort of a risk that needs to be managed.

Limitations and Future Research Avenues

The agent-based simulation allows modelling a supply chain system that contains a population of buyers and a population of suppliers. However, the simulation, like all other quantitative modelling methods, is limited by the assumptions used in building the model, which simplify the underlying empirical phenomenon. First, we assumed that each buyer required only one supplier. Second, due to the nature of the empirical data used to build this simulation, we only considered the effect of buyers' decisions on the population of suppliers, although other factors such as horizontal relationships among suppliers within the population or actions of other stakeholders (external to the supplier population) could also affect the presence of SSR in a supplier population (Hollos et al., 2012, Tong et al., 2018). Future research may extend our study and investigate the presence of SSR in more complex supply networks that include other stakeholders who can influence the supplier behavior.

Third, in our simulation, buyers could freely switch to any supplier in the population without considering switching costs. We also assumed that the suppliers had unlimited capacity and could serve all the buyers that switched to them. Besides, although buyer and supplier power and dependence are relational and potentially mutual between the two parties (Cox, 2001), the scope

of our experiment was limited to scenarios in which the supplier's power was set as low and only the unilateral effect of high and low levels of buyer's power was explored. Such considerations are likely to influence decision-making of both buyers and suppliers in actual situations. Future research should consider how various constraints faced by buyers and suppliers may influence the evolution of supplier populations and the presence of SSR in those populations. Fourth, it is noteworthy that even in simple dyadic buyer-supplier relations, the buyers may not be fully aware of various sustainability-related misconduct within their supply chains (Meinlschmidt et al., 2016). Although we took precautions and included the visibility as a parameter in our study, we assumed that all types of supplier misconduct can be identified with the same level of probability. Future research is encouraged to distinguish among various types of sustainability-related misconduct to understand what types of misconduct are harder to identify in supplier operations.

Finally, future studies could validate the testable propositions of this study through collection of primary or secondary data or multiple case studies. Similar multi-method studies are also encouraged to investigate the phenomenon from the suppliers' perspective, for example how a decrease in the probability of misconduct by one supplier can change the average and maximal probabilities of the misconduct in the supplier population given the competitiveness of such environments.

Conclusions

This research relied on organizational population ecology theory to study the evolution of a supplier population that faces buyers who seek to eliminate SSR in their industry. Specifically, we used an agent-based simulation built using experimental data to investigate how buyer efforts affected the presence of SSR in a supplier population, thus affecting the characteristics of supplier population. Our study revealed (i) how the buyer population characteristics could change to what

degree and how quickly their cumulative efforts led to population-wide changes in the level of the risk and (ii) how these efforts affected the composition and density of the supplier population.

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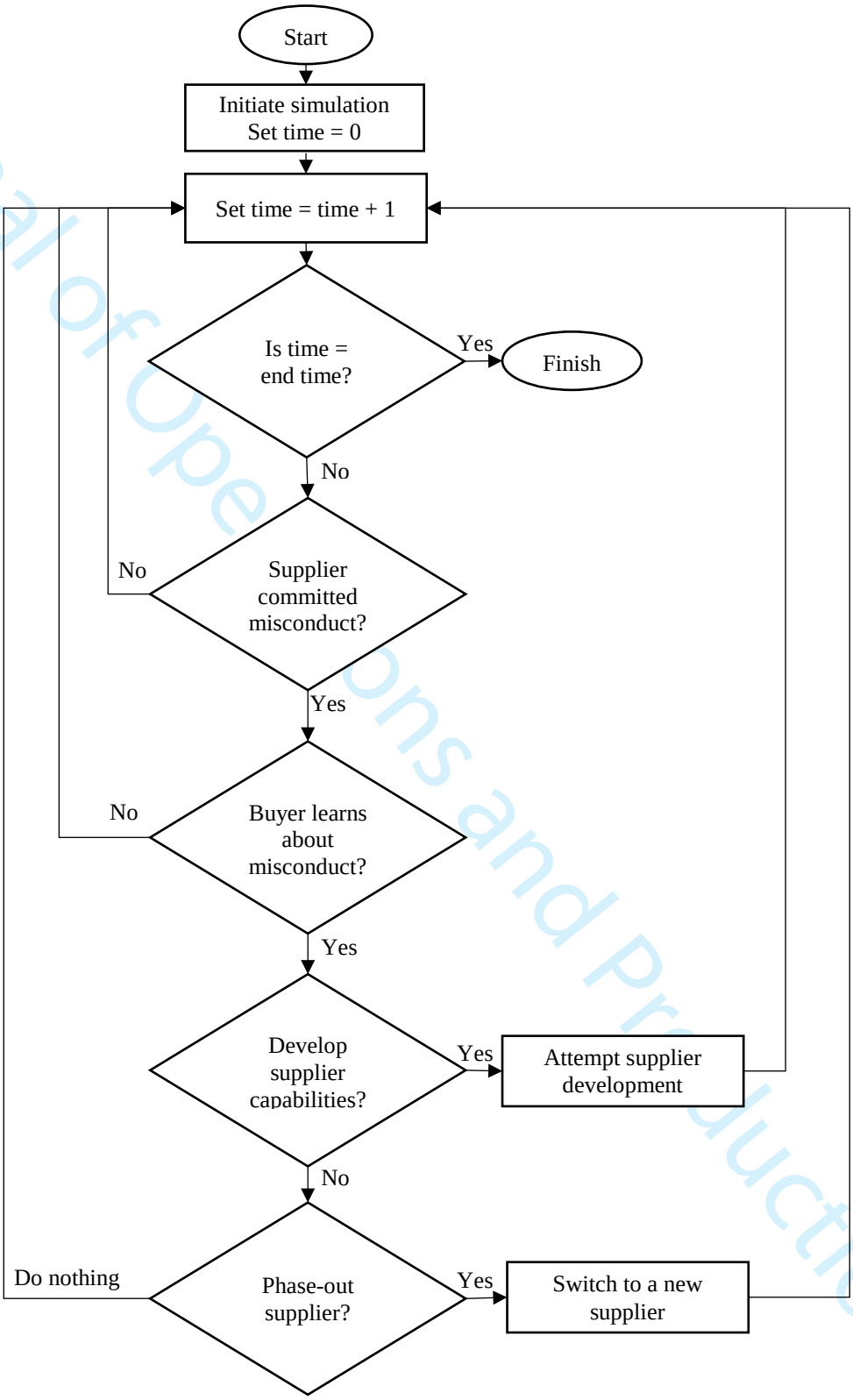
Appendix I. Simulation flowchart



Appendix II. Simulation runs with different values for simulation parameters

The simulation results discussed in the main body of the manuscript and reported in Table 4 are based on a number of assumptions regarding starting values of simulation parameters (as reported in Table 3). This Appendix presents the simulation results after changing the starting values for these parameters to support the robustness of our results. The results reported below are related to repeated analyses with (A) different initial values for the probability of supplier misconduct P_{MC}, (B) different initial values for the probability of learning P_V, (C) different number of buyer-supplier dyads N, and (D) different values for the number of time periods the simulation runs i. Simulation outcomes reported below are consistent with the results reported in Table 4 and therefore show robustness to changes in the analysis.

A. Simulation outcomes for analysis with different values for initial P_{MC}								
Parameter values: Initial P_{MC} = 0.50; P_V = 0.50, N = 20, i = 60								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.052	0.148	0.059	0.127	0.019	0.038	0.053	0.230
Max. P_{MC}	0.251	0.461	0.264	0.439	0.063	0.193	0.220	0.500
% Active suppliers	0.543	0.756	0.459	0.512	0.852	0.580	0.456	0.519
Parameter values: Initial P_{MC} = 0.90; P_V = 0.50, N =20, i = 60								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.050	0.246	0.049	0.157	0.018	0.027	0.043	0.312
Max. P_{MC}	0.241	0.810	0.230	0.613	0.067	0.116	0.181	0.831
% Active suppliers	0.479	0.716	0.358	0.370	0.837	0.512	0.301	0.358
B. Simulation outcomes for analysis with different values for P_V								
Parameter values: Initial P_{MC} = 0.70; P_V = 0.30, N =20, i = 60								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.101	0.341	0.097	0.223	0.023	0.072	0.086	0.407
Max. P_{MC}	0.459	0.696	0.448	0.653	0.096	0.348	0.391	0.696
% Active suppliers	0.546	0.781	0.457	0.505	0.853	0.574	0.431	0.546
Parameter values: Initial P_{MC} = 0.70; P_V = 0.70, N = 20, i = 60								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.041	0.137	0.050	0.106	0.017	0.025	0.050	0.204
Max. P_{MC}	0.232	0.554	0.247	0.405	0.059	0.113	0.254	0.612
% Active suppliers	0.513	0.680	0.413	0.395	0.857	0.575	0.408	0.436
C. Simulation outcomes for analysis with different values for N								
Parameter values: Initial P_{MC} = 0.70; P_V = 0.50, N = 15, i = 60								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.061	0.215	0.056	0.165	0.016	0.037	0.065	0.267
Max. P_{MC}	0.276	0.640	0.235	0.538	0.054	0.160	0.244	0.639
% Active suppliers	0.511	0.725	0.435	0.451	0.845	0.571	0.399	0.427
Parameter values: Initial P_{MC} = 0.70; P_V = 0.50, N = 25, i = 60								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.041	0.222	0.066	0.155	0.018	0.036	0.056	0.289
Max. P_{MC}	0.209	0.690	0.349	0.606	0.075	0.199	0.287	0.670
% Active suppliers	0.520	0.733	0.427	0.462	0.831	0.542	0.403	0.460
D. Simulation outcomes for analysis with different values for i								
Parameter values: Initial P_{MC} = 0.70; P_V = 0.30, N = 20, i = 50								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.080	0.223	0.085	0.193	0.024	0.072	0.091	0.311
Max. P_{MC}	0.471	0.691	0.423	0.627	0.129	0.385	0.433	0.700
% Active suppliers	0.694	0.806	0.537	0.584	0.836	0.677	0.490	0.591
Parameter values: Initial P_{MC} = 0.70; P_V = 0.70, N = 20, i = 70								
Scenario	1	2	3	4	5	6	7	8
Avg. P_{MC}	0.055	0.144	0.070	0.144	0.015	0.045	0.068	0.239
Max. P_{MC}	0.345	0.604	0.382	0.582	0.067	0.254	0.382	0.656
% Active suppliers	0.660	0.768	0.529	0.525	0.809	0.642	0.497	0.535

Table 1. The odds values of buyer's SSR Strategies

Decision Parameters			Decision Odds Values	
Buyer's Power	Buyer's Resource Scarcity	Risk Impact	Decision: Develop	Decision: Phase-out
High	High	High	0.24	0.16
		Low	0.08	0.02
	Low	High	2.43	0.14
		Low	0.31	0.14
Low	High	High	0.27	0.53
		Low	0.10	0.25
	Low	High	0.35	1.33
		Low	0.05	0.28

Table 2. Simulation scenarios

Scenario	1	2	3	4	5	6	7	8
Risk impact	High	Low	High	Low	High	Low	High	Low
Buyer's power	High	High	High	High	Low	Low	Low	Low
Buyer's resource scarcity	High	High	Low	Low	High	High	Low	Low

Table 3. Simulation parameters

Parameters	Notation	Value
Number of buyer-supplier dyads	N	20
Probability of supplier misconduct	P_{MC}	0.70
Visibility of supplier misconduct	P_V	0.50
Risk impact	I	{0,1}
Buyer's power	P	{0,1}
Buyer's resource scarcity	R	{0,1}
Number of time periods	i	60

Table 4. Simulation outcomes

Scenario	1	2	3	4	5	6	7	8
Risk impact	High	Low	High	Low	High	Low	High	Low
Buyer's power	High	High	High	High	Low	Low	Low	Low
Buyer's resource scarcity	High	High	Low	Low	High	High	Low	Low
Avg. P_{MC}	0.051	0.221	0.061	0.145	0.019	0.039	0.063	0.303
Max. P_{MC}	0.277	0.672	0.294	0.515	0.066	0.222	0.290	0.681
% Active suppliers	0.623	0.839	0.524	0.568	0.884	0.677	0.484	0.584

Figure 1 - The evolution of average probability of misconduct among active suppliers over time

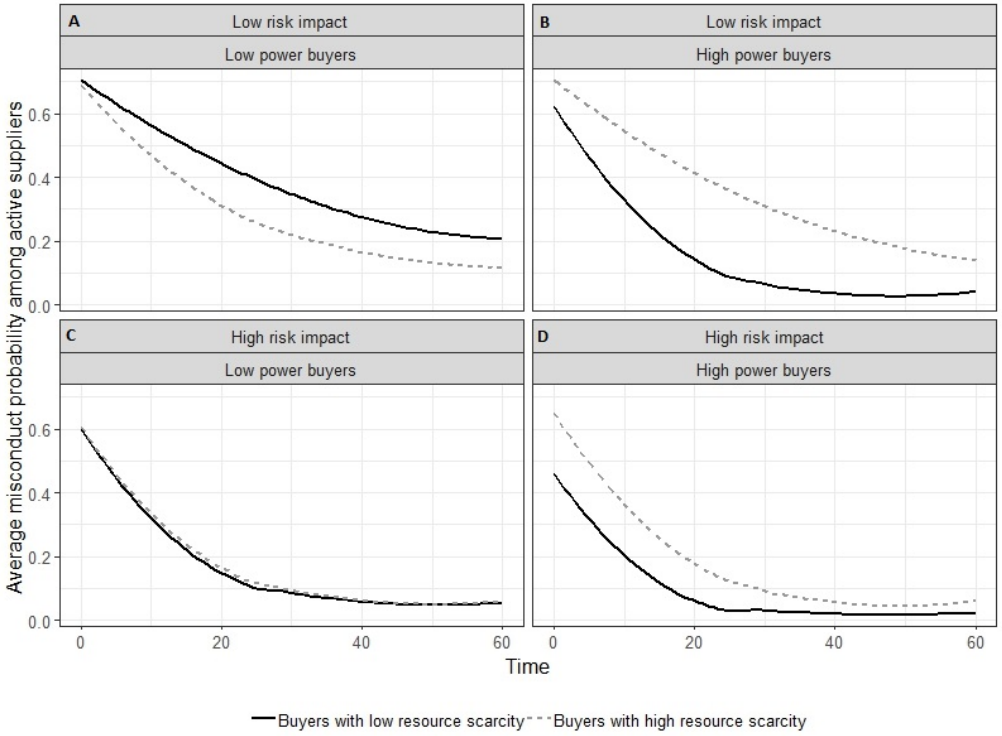


Figure 2 - The evolution of maximal probability of misconduct among active suppliers over time

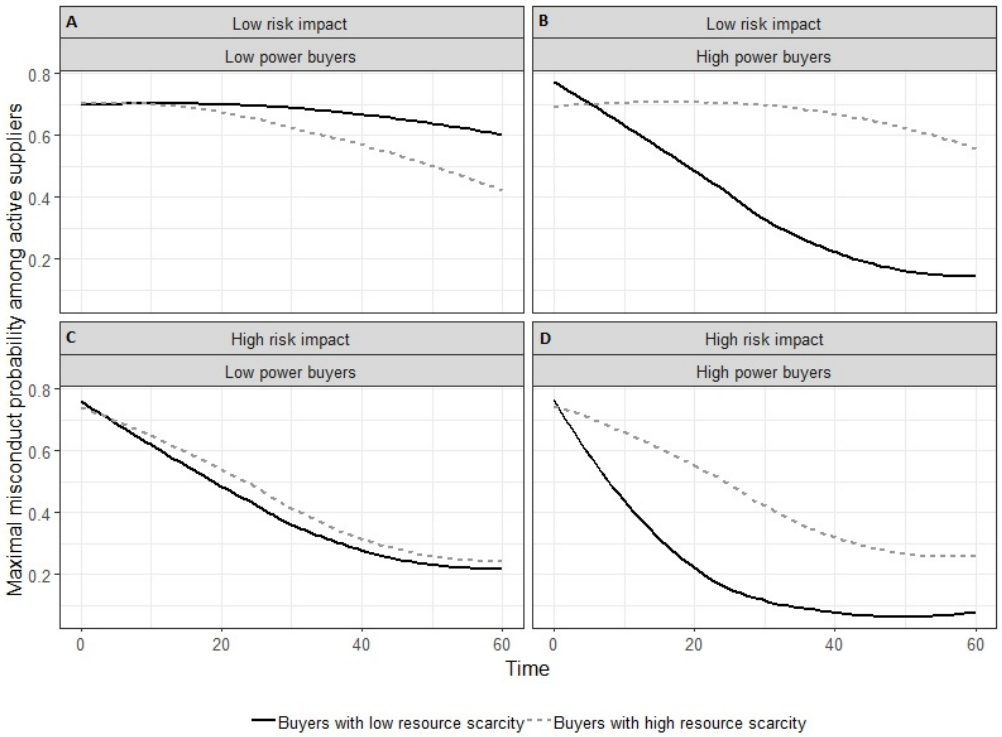


Figure 3 - The evolution of active supplier population over time