Managing Sustainability Risks in Multi-Tier Supply Chains:
An Agent-Based Simulation Study[1]

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Abstract

Many modern firms strive to become sustainable. To this end, the firms are required to improve not only their own environmental and social performance but also the performance of their suppliers. Using an agent-based simulation and building on population ecology theory, this working paper explores how buyers' exposure to sustainability risks and their subsequent risk management strategies can lead to industry-wide adherence to sustainability by the suppliers. We use previously collected experimental data on managing sustainability risks to assess how buyer populations with different characteristics can change the presence of sustainable and unsustainable business practices in a population of suppliers.

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

Introduction

The institutional environment that regulates sustainable business practices is changing rapidly (Rugman and Verbeke 1998). At the same time, non-governmental organizations and activist groups are increasingly using boycotts, demonstrations, social media, and other tactics to expose social and environmental management issues within supply chains and link them back to the buying firms, hereafter *buyers* (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 the firm's efforts to become sustainable. Such a risk associated with a firm's suppliers is referred to as supplier sustainability risk (Hofmann et al. 2014).

Foerstl et al. (2010) define supplier sustainability risk as "the risk of corporate reputational damage to the buying firm, caused by supplier [sustainability-related]

[1] This paper is a working paper in which instead of modelling a multi-tier supply chain, we focus on a network of multiple single-tier supply chains to produce more externally valid results.

misconduct[s]" (p. 118). It may occur when salient stakeholders hold a buyer accountable (Mitchell et al. 1997) for supplier misconducts related to the natural environment or social communities (Amaeshi et al. 2008; Parmigiani et al. 2011; Klassen and Vereecke 2012). As such, supplier sustainability risk is the cumulative likelihood of these events and their consequences (Roehrich et al. 2014). To avoid any harm to their reputation or economic standing, many buyers attempt to manage the supplier sustainability risks (Hajmohammad and Vachon 2016). Their actions are expected to change suppliers' population in their industries: some suppliers susceptible to environmental change are likely to be selected out of the population, while new organizational forms (e.g., responsible suppliers) are likely to emerge (Connelly et al. 2011).

In this exploratory study, we take the organizational ecology perspective (Hannan and Freeman 1977) to study the sustainability risk phenomenon and its effects at the industry level. Specifically, we explore *how the dyadic–level risk management strategies pursued by buyers affect the mix and density of suppliers' population.* To address the research questions, we use previously collected experimental data on managing supplier sustainability risks to build an agent-based simulation and assess the effect of evolutionary processes on the presence of sustainable and unsustainable business practices in a population of suppliers. We choose to employ agent-based simulation due to its ability to capture the complex dynamics of modern supply chains and probabilistic nature of sustainability risks.

The results of this working paper demonstrate how various actions of a buyer population change the characteristics of the supplier population. Specifically, we show how some buyers remove sustainability risks from their supplier population by eliminating the presence of these risks in the whole population, while other buyers achieve lower exposure to sustainability risks by sourcing from a small number of low-risk suppliers. Finally, we show what types of buyers are the most effective at eliminating sustainability risks from their supplier population.

Population Ecology of Organizations and Density Dependence Theory

Population ecology theory focuses on the population of organizations and attempts to explain the emergence, evolution, and demise of organizational forms within the population in response to their environment over time. 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). Population ecology theory challenges the prominent view that individual organizations and their decision makers learn and internally adapt to changes in the environment without consequence; instead, it suggests that organizational forms change at the population level and their evolution and survival is based on environmental selection of those organizations that best fit their environment (van Witteloostuijn 2000). More specifically, the population's composition changes through the processes of variation, selection, retention, and competition (Aldrich 1979): the organizations tolerating the pressures survive or are "selected into" the population and the rest are "selected out".

One of the most established organizational population models posits that the mortality rate of organizations in a population depends on the number of similar operating organizations at any point in time within the same population (Hannan and Carroll 1992). As the number of organizations with similar characteristics (i.e., population density) increases, the environment perceives them as a legitimate and natural organizational form and allows their growth. This effect, however, has a saturation point. When the population contains a high number of these organizations, appearance of similar organizations does not increase the environment's perception of these organizations any further. Thus, after the saturation point, their population density can remain the same or even decrease due to competitive pressures.

In this research, we employ the population ecology theory in the context of supplier sustainability risk management. We explore how attempts of buyers to manage sustainability risks among their suppliers affect the characteristics of those suppliers and their survival rate. Specifically, we focus on the situations when an industry contains high-risk suppliers, i.e. suppliers that are likely to expose buyers to sustainability risks. We, then, explore conditions under which the environment (buyers in the industry) tolerate their presence and continue sourcing from those suppliers.

Supplier Sustainability Risk at the Buyer-Supplier Dyad Level

Strategies to Manage Sustainability Risk

A buyer's ability in managing supplier sustainability risk is critical to its competitiveness and long-term success (Eccles et al. 2007). Although it may try to do it in a number of ways, its responses would fit into three generic categories of risk management strategies: avoidance, acceptance, and mitigation (Ritchie and Brindley 2007; Blome and Schoenherr 2011; Lemke and Petersen 2013). The focus of this study is on operational-level strategies which a buyer may undertake to manage the supplier sustainability risk of its supplier. Foerstl et al. (2010) suggest that such responses include supplier phase-out and sustainable supplier development. By implementing supplier phase-out, a buyer terminates the relationship with the incumbent risky supplier and switch to another alternative supplier with a clean sustainability record. Hence, supplier phase-out fits into the risk avoidance category (Jüttner et al. 2003), which entails the elimination of risk by withdrawing from the risky situations.

Sustainable supplier development initiatives, on the other hand, fit into risk mitigation category (Ritchie and Brindley 2007). They are defined as the buyers' plans and strategies to integrate the ecological and social issues into supply management process to improve the ecological and social performance of the suppliers (Krause et al. 2007; Klassen and Vereecke 2012). Therefore, they are the buyers' means for reducing the probability of supplier sustainability risk by enhancing suppliers' ecological and social performance through direct interaction with them and implementation of jointly-developed ecological and social solutions (Golicic and Smith 2013). These initiatives encompass a broad range of activities such as providing training programs to suppliers, compensating them for the costs associated with their compliance (e.g., joint investments in environmental friendly equipment), and sponsoring ecological or social summits for suppliers to encourage the sharing of information and experience (Vereecke and Muylle 2006).

Finally, in addition to the proactive strategies suggested by Foerstl et al. (2010), we also include risk acceptance as a reactive strategy that buyers might use to manage supplier sustainability risk. Taking on this strategy, buyers simply retain the risk by sufficing to comply with the regulations and taking no further actions and budgeting for dealing with the consequences of the potential risk event should it happen at some point (Sodhi and Tang 2012).

Predictors of Buyers' Choice amongst Risk Management Strategies

Based on resource dependence (Pfeffer and Salancik 2003) and agency theories (Eisenhardt 1989), Hajmohammad and Vachon (2016) suggest that there are two major predictors of buyers' risk management strategy choice: the level of supplier sustainability risk as well as the level of supplier dependence on the buyer. In addition, buyers competing in the same industry with similar external dynamics, such as stakeholder salience, supply base, and buyer-supplier dependence structure appear to pursue different risk management strategies. One explanation for this is that, despite the similarities in their external environment, these organizations differ in their resource endowments, especially the level of their organizational slack (Voss et al. 2008). Therefore, slack resources available to buyers are considered as another predictor of their choice amongst risk management strategies.

Buyer power- According to resource dependence theory, organizations are not self-sufficient and depend on each other for resources, and such interdependency introduces uncertainty into their decision-making environment (Pfeffer and Salancik 2003). As a result, they adjust their behaviors to acquire and maintain their required resources and try to reduce their environmental uncertainties and dependencies by means of control mechanisms (Hillman et al. 2009). Resource dependence theory predicts that the type of such control mechanisms depends on the level and nature of dependence they develop, and the relative power of all players (Pfeffer and Salancik 2003). Consequently, in a supply chain context, the buyers' risk management strategies applied as control mechanisms to mitigate the supplier sustainability risks depend on the level of buyer's power over the supplier.

Supplier sustainability risk- Supplier sustainability risk is the cumulative likelihood and consequence of a series of events: occurrence of a sustainability-related misconduct in buyer's supply base, stakeholders' detection of the misconduct and their attribution of the misconduct responsibility to the buyer. Buyers' response to this cumulative risk depends on their perception of the level of the risk (March and Shapira 1987; Sitkin and Weingart 1995).

Resources scarcity- 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). Slack resources can ease the adoption of a proactive strategic behavior and influence managerial decision outcomes (Singh 1986). Specifically, financial slack allows the buyers to invest in initiatives with positive performance implications such as risk management strategies that do not have an immediate pay-off and require a longer investment horizon (George 2005). To implement the proactive risk management strategies, buyers will have to change the scope and/or volume of their supply management processes and activities. Thereby, carrying them out with scarce resources would be very challenging for the buyers. In other words, the type of strategy they select may well be limited by the amount of resources at their disposal.

Methodology

The aim of this study is to investigate how the decisions of buyers about supplier sustainability risks shape the characteristics of the supplier population. Specifically, we seek to understand how many suppliers remain in the population and how their propensity to expose buyers to sustainability risks changes over time. To address these questions, we have selected agent-based simulation (Wilensky and Rand 2015) as the research methodology for this study. This methodology can offer a valid representation of a complex, dynamic supply chain management phenomenon. Agent-based modeling is a widely-used approach when the phenomenon under study involves a "collection of autonomous decision-making entities, agents" (Bonabeau 2002) such as buyers and suppliers. It is a bottom-up approach, where agents' rules of behavior are specified to understand the dynamics of an entire system (e.g., a population of buyers sourcing from a the population of suppliers) (Macal and North 2010), and where agents (e.g., buyers and suppliers) can possess heterogeneous attributes, exhibit uncertain behavior, form networks, 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.

We use previously collected empirical data on managing supplier sustainability risks to build an agent-based simulation. 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, we use the collected data from a vignette-based experiment conducted in 2014-2015 to ground the simulation assumptions and thus ensure input validity. The experiment focused on a buyer-supplier dyad and showed how the decisions the buyers take to manage the sustainability risks are affected by (1) the risk impact, i.e. whether the occurred supplier misconduct will lead to a buyer experiencing significant reputational and financial losses caused by the materialized sustainability risk, (2) resource scarcity, i.e. whether a buyer has resources available to manage the supplier misconduct, and (3) they buyer's power, i.e. whether a buyer has the ability to influence the supplier. After considering these factors, a buyer then decides whether it should (1) attempt to develop supplier capabilities or (2) phase-out the supplier. Both actions are oriented toward decreasing the probability of experiencing future supplier misconducts. Table 1 summarizes how odds of each decision are influenced by three parameters outlined above. If a buyer chooses to neither develop supplier capabilities nor phase-out the supplier, we then assume that it chose not to address the occurred supplier misconduct.

Table 1 - The odds of decision a buyer can make after occurred supplier misconduct

Parameters		Decisions	Risk Impact: High	Risk Impact: Low
Buyer's Power	High	Develop	0.35 (High Resource Scarcity)	0.08 (High Resource Scarcity)
			2.43 (Low Resource Scarcity)	0.14 (Low Resource Scarcity)
		Phase-out	1.33 (High Resource Scarcity)	0.02 (High Resource Scarcity)
			0.13 (Low Resource Scarcity)	0.31 (Low Resource Scarcity)
	Low	Develop	0.27 (High Resource Scarcity)	0.10 (High Resource Scarcity)
			0.35 (Low Resource Scarcity)	0.05 (Low Resource Scarcity)
		Phase-out	0.53 (High Resource Scarcity)	0.25 (High Resource Scarcity)
			1.33 (Low Resource Scarcity)	0.28 (Low Resource Scarcity)

Using these dyadic data, we built an agent-based simulation in NetLogo. The simulation starts at $t = 0$ with a population of N buyer-supplier dyads. Each supplier is assigned a probability of misconduct P_{MC} that is capped at the set value of C: $\forall P_{MC} \leq C$. Drawing from the population ecology theory, we manipulate C to represent different densities of high-risk suppliers and low-risk suppliers in the population. In each dyad at each subsequent period $t = 1,2,3$ ... a buyer procures from its supplier and faces the probability of supplier misconduct P_{MC} that was assigned to its supplier. We take into account that not all occurrences of supplier misconducts can be visible to a buyer by introducing 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 $V: V \in [0,1]$ as the probability of learning about the occurred supplier misconduct.

If a buyer learns about occurred supplier misconduct, it then makes decisions regarding the responsible supplier. Depending on a buyer's degree of sustainability risk $S : S \in \{0,1\}$ (Wilensky and Rand 2015), its available resources $R : R \in \{0,1\}$, and its power $P : P \in \{0,1\}$, the buyer will decide whether to (1) attempt to develop supplier capabilities, (2) phase-out this supplier; or (3) do nothing. If the buyer decides to develop supplier capabilities, the simulation then decreases the probability of supplier misconduct by a random value. If the buyer decides not to take this action, it then considers whether it should phase-out this supplier. If the firm decides to phase-out the supplier, it then switches to another supplier. Specifically, it seeks to find a supplier that is currently supplying to another buyer and has not caused any misconduct at this time period. The combined actions of all buyers within the simulation network will then shape the population of the suppliers and affect the presence of sustainability risks in the suppliers' population.

At each time period, the simulation tracks two outcomes. First, it 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 have a buyer. If a buyer, however, experiences supplier misconduct, it can switch to another supplier and overtime some suppliers may end up without buyers. The first outcome, the proportion of active suppliers, refers to the proportion of suppliers with at least one buyer, referred to as active suppliers. The second outcome is an average probability of supplier misconduct among those active suppliers.

Simulation Results

The findings of this working paper focus on the evolution of supplier population over time. Figures 1 and 2, correspondingly, track the average and maximal probabilities of supplier misconduct among suppliers that supply to at least one buyer at that time period. The average probability decreases at a decreasing rate, saturating after a certain point regardless of the type of external environment suppliers face, i.e., for all characteristics of buyer populations. It is not surprising to see that having powerful buyers with resources will push the supplier population's average probability of misconduct at the highest rate to the lowest values. Interestingly, such buyer populations differ in how they achieve this goal. Buyers that face high risk impact lower this probability by developing their suppliers; in contrast, buyers that face low risk impact lower this probability by switching to better suppliers. In other conditions, the process of diminishing the average probability is a slower process that converges at a higher probability value. These findings suggest that it is necessary for buyers to have both power and resources to make rapid improvements in an industry.

What is more surprising is that only the buyer population with power and resources is effective at eliminating suppliers with the worst propensity to misconducts. Specifically, the maximal probability of misconduct is diminished at a rapid rate only if the buyers are powerful and resourceful. In other words, only in industries where buyers have both power and resources should one expect to see the elimination of sustainability risks. In other words, these buyers may achieve lower probability of misconduct on average but some of them may still face significant sustainability risks. Interestingly, these populations of buyers can become more effective at removing suppliers with high probability of misconduct from their industry if they face high risk impact.

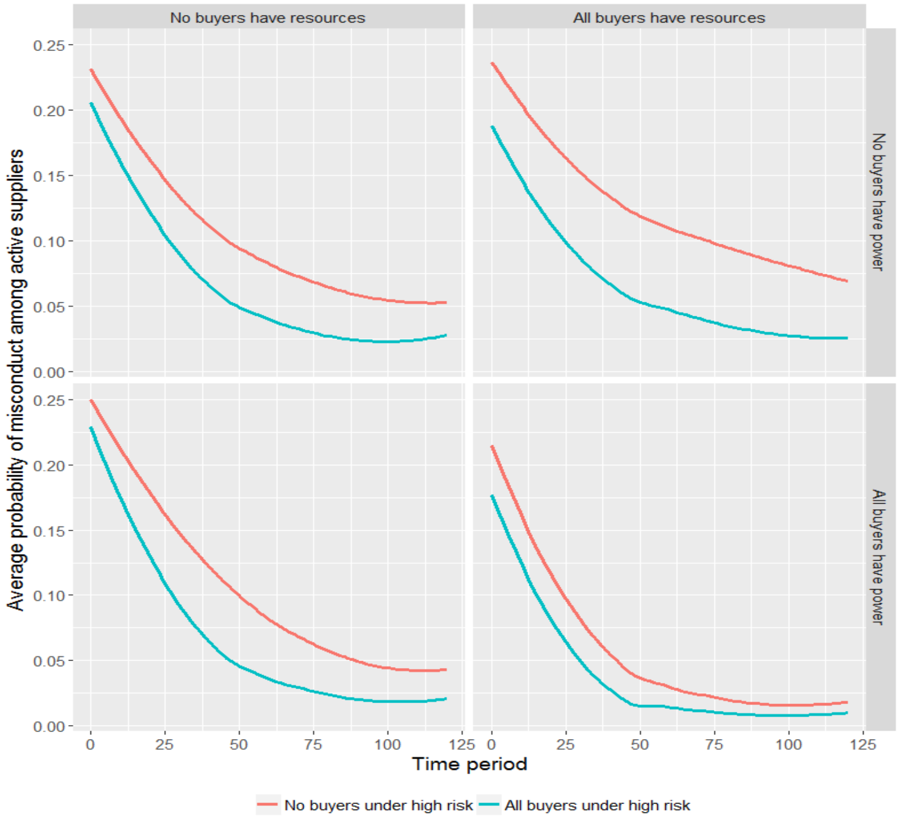

Figure *1 - The evolution of average probability of misconduct among active suppliers over time (visibility is set at 50%)*

Figures 1 and 2 show that various buyer populations can decrease their exposure to sustainability risks but they vary greatly at the speed and the degree of change. Figure 3 shows how the efforts of buyers affect the population density of suppliers. Specifically, the figure shows that only powerful buyers with resources and under high risk impact are capable of eliminating the probability of misconduct of almost the whole supplier population. Whereas buyers that lack these characteristics reduce their exposure to sustainability risks by switching to a sub-population of suppliers associated with low probabilities of misconduct. For instance, when buyers lack power, they are less likely to engage in supplier development and therefore manage their exposure to sustainability risks by switching to better suppliers.

Conclusion

This study contributes to the emerging but rather sparse literature on sustainability risk by exploring how the efforts of buyers can lead to industry-wide adherence to sustainability by the suppliers. Using an agent-based simulation and previously collected empirical data, this working paper reveals that powerful and resourceful buyers, compared to other buyer populations, push the supplier population's average probability of misconduct to the lowest values and at the highest rates. Interestingly, such buyers differ in how they achieve this outcome: those facing high risk impact reduce the misconduct probability by developing their suppliers, while those facing low risk impact do the same by switching to better suppliers. In addition, the simulation results show that the supplier sustainability risk can only be eliminated effectively in an industry if the buyer population is both powerful and resourceful.

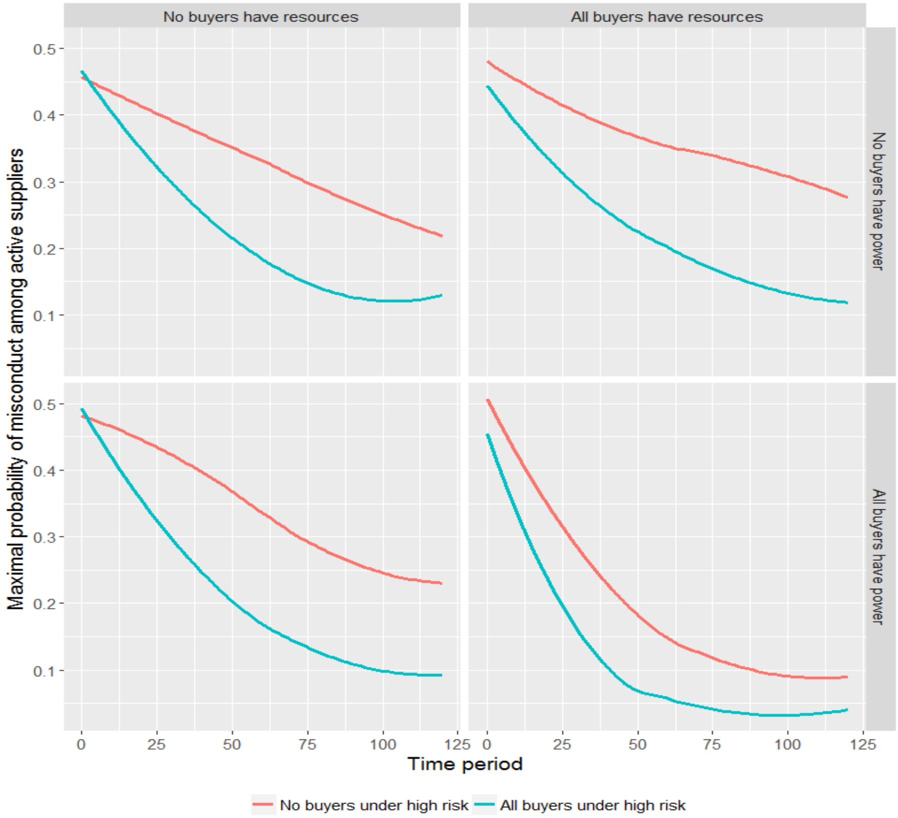

Figure 2 - The evolution of maximal probability of misconduct among active suppliers over time (visibility is set at 50%)

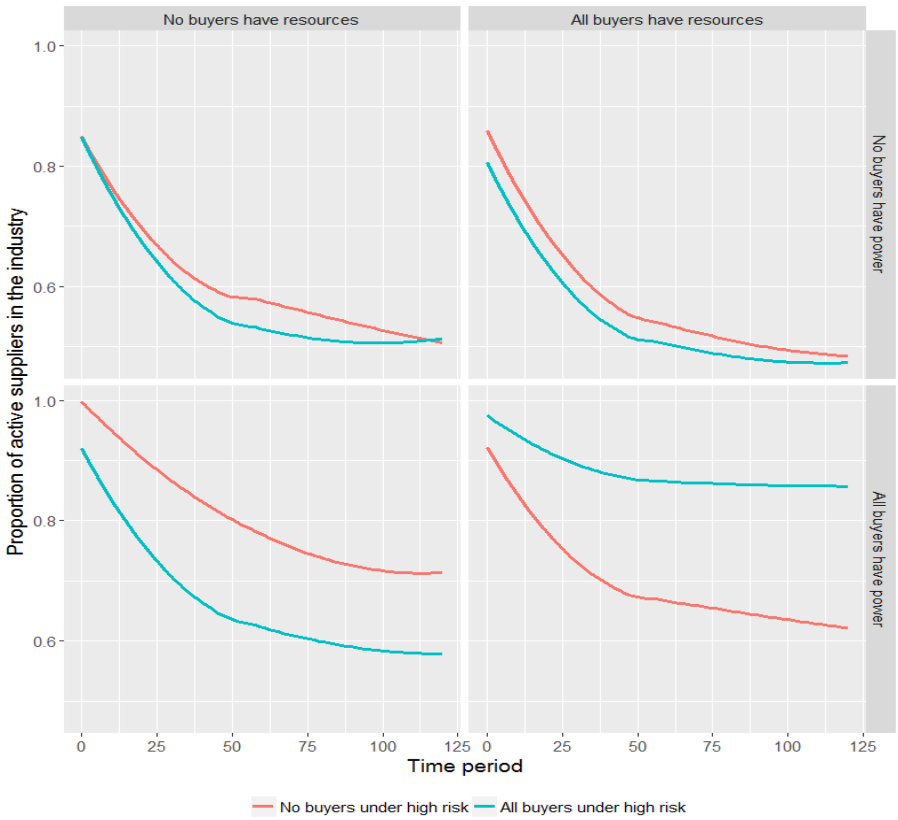

Figure 3 - The evolution of population density over time (visibility is set at 50%).

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