Journal of Environmental Management 254 (2020) 109721

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

A mechanism design approach to a buyer's optimal auditing policy to induce responsible sourcing in a supply chain

Hamid Zarei [a], Morteza Rasti-Barzoki [a,*], Ilkyeong Moon [b]

[a] Department of Industrial and Systems Engineering, Isfahan University of Technology, Isfahan, 84156-83111, Iran
[b] Department of Industrial Engineering and Institute for Industrial Systems Innovation, Seoul National University, Seoul 151-744, South Korea

ARTICLE INFO

Keywords:
Sustainability
Responsible sourcing
Auditing
Supply chain transparency
Game theory
Mechanism design

ABSTRACT

Responsible sourcing refers to the compliance of suppliers with environmental and social standards. In today's supply chains, buyers and external stakeholders use auditing mechanisms to induce responsible sourcing. For the first time, this paper investigates the effect of a buyer's audits on the tactical decisions of supply chains. We address a repeated game with one buyer and one critical supplier. At the strategic stage, the buyer chooses the optimal auditing efforts to induce responsible sourcing. At the tactical stages, the buyer and supplier compete with each other for their profit margins, while the buyer also determines the quantity of production. Moreover, the supplier chooses between responsible and irresponsible production. Two auditing mechanisms are defined for the buyer: strong incentive compatibility (SIC) and weak incentive compatibility (WIC). The effectiveness and backfiring conditions for these auditing mechanisms are identified. The former denotes that the mechanism can induce responsible sourcing, while the latter denotes the conflict between supply chain transparency and responsible sourcing. The results show that the supplier requires an efficiency wage for compliance with responsible sourcing standards. We find that auditing mechanisms in supply chains face an unintended consequence. Higher auditing efforts by the buyer reduce the supplier's wholesale price. This reduction may offset the greater potential for discovery obtained by higher auditing efforts. We also show that the effect of consumer awareness on responsible sourcing is not straightforward and depends strongly on the buyer's auditing mechanism. If the buyer chooses the SIC (WIC) auditing mechanism, consumer awareness always favors (threatens) responsible sourcing. Finally, this research suggests that coordination between buyers and external stakeholders contributes greatly to responsible sourcing.

1. Introduction

> "Consumers and stakeholders increasingly want to know where their food comes from, what it contains and how it was made. We are proud to be implementing responsible sourcing and to answer our consumers' questions. Transparency in our supply chains and responsible sourcing of our materials are essential to ensuring our sustainable future."
>
> Nestlé Corporation.[1]

The world is threatened by crises such as natural resource deficits, population growth, environmental pollution, and social issues. Concerned researchers and activists have suggested the concept of *sustainability* to deal with these crises. Sustainability involves three main dimensions: environmental, economic, and social aspects (Elkington, 1998; Tseng and Hung, 2014). The social aspect of sustainability has received less attention than the other two aspects (Sinayi and Rasti-Barzoki, 2018).

Responsible sourcing, also known as ethical sourcing, is an important component of sustainability. This concept refers to the compliance of suppliers with environmental and social standards (Agrawal and Lee, 2016). In recent years, responsible sourcing has frequently generated conflict between buyers and their suppliers, especially in developing countries. Due to financial or reputational considerations, buyers aim to adopt responsible sourcing. The main driver for the progress of these initiatives is consumer social and environmental awareness about the consequences of irresponsible sourcing (Agrawal and Lee, 2016). In

* Corresponding author. Tel.: +9831 3391 1480; fax: +9831 3391 5526.
E-mail addresses: hamid.zarei@in.iut.ac.ir (H. Zarei), rasti@cc.iut.ac.ir, rasti@snu.ac.kr (M. Rasti-Barzoki), ikmoon@snu.ac.kr (I. Moon).
[1] https://www.nestle.com/csv/impact/rural-livelihoods/responsible-sourcing.

https://doi.org/10.1016/j.jenvman.2019.109721
Received 28 October 2018; Received in revised form 5 August 2019; Accepted 15 October 2019
Available online 11 November 2019
0301-4797/

contrast, suppliers do not usually follow responsible sourcing principles because they are expensive to implement. The history of the relationship between Apple and Foxconn is an example of this conflict. Foxconn, a Taiwanese supplier to Apple, faced a major crisis in its facilities in 2011. One of the factories producing the iPad 2 exploded. In addition, a 20-year-old employee committed suicide a week after the explosion (Brownlee, 2011). In response to tragedies like this and other similar events, buyers, governments, and other stakeholders are seeking to implement mechanisms to induce responsible sourcing.

In today's supply chains, many buyers use auditing mechanisms to induce responsible souring (Agrawal and Lee, 2016). Walmart usually audits its suppliers, and future sourcing from a supplier depends on the results of these audits (Plambeck and Denend, 2010). As another example, Apple publishes annual *Apple Supplier Responsibility* reports. These reports disclose the supplier list, audit results, and training programs. Apple claims that the goal of these programs is to better monitor and improve conditions at the suppliers' factories (Chen and Baddam, 2015). In the *Apple Supplier Responsibility 2013 Progress Report*, the company announced that it would terminate sourcing from a Chinese supplier that had employed underage labor (Apple, 2013). In addition, in the *Apple Supplier Responsibility 2018 Progress Report*, the company announced that suppliers were audited and evaluated on three criteria: *labor and human rights*, *health and safety*, and the *environment* (Apple, 2018).

In addition to buyers' internal auditing efforts, some supply chains are subject to external auditing efforts, the third-party assurance phenomenon (Daddi et al., 2016; Gürtürk and Hahn, 2016; Park and Brorson, 2005). These external audits are provided by stakeholders such as governmental and non-governmental organizations (NGOs), labor unions, and other activists. Two examples of these stakeholders are the Fair Factories Clearinghouse[2] and Better Work.[3] There is an explicit difference between buyers that provide internal auditing efforts and stakeholders who provide external auditing efforts: buyers influence other decisions within the supply chain, such as purchasing and production, while external stakeholders do not.

With regard to buyers' internal and stakeholders' external auditing efforts within today's supply chains, this paper addresses the following research questions:

Question 1. Under what conditions are buyers' auditing mechanisms ineffective in inducing responsible sourcing in supply chains?
Question 2. Under what conditions does increasing the total number of external auditors not result in better conditions for responsible sourcing?
Question 3. How does consumer awareness influence the effectiveness of buyers' auditing mechanisms?

In addition to responsible sourcing, transparency is another challenge of today's supply chains. Stakeholders push for transparent supply chains that rely on responsible sourcing. One example of these types of stakeholders is anti-sweatshop campaigns (Egels-Zandén and Hansson, 2016) that attempt to hold buyers such as Nike and Adidas responsible for improving labor conditions at their supplier's firms (Bartley, 2007) and also increasing the transparency of their supply chains (Doorey, 2011). The quotation from Nestlé Corporation at the beginning of this section also demonstrates the importance of this goal to buyers. An important question arises about these campaigns: Do they always achieve their twin goals simultaneously or are there conditions in which increasing supply chain transparency conflicts with increasing supplier responsibility? The fourth question is as follows:

Question 4. How do responsible sourcing and a buyer's transparency interact with each other?

In order to induce responsible sourcing, there may be more than one alternative for a buyer's auditing mechanism. According to the "no free lunch" principle, each alternative offers some advantages but imposes some disadvantages on the related stakeholders. What are the criteria for this comparison? The fifth research question is as follows:

Question 5. If there is more than one auditing mechanism available to induce responsible sourcing, how are these alternatives compared with each other?

The objective of this paper is to study a buyer's auditing mechanism, investigate its effectiveness to induce responsible sourcing, and unravel how this mechanism interacts with consumer awareness and external auditing efforts within the supply chain. In order to conduct these investigations, we study the effect of the buyer's audits on the purchasing and production decisions of the supply chain; the buyer's order quantity and profit margin, and the supplier's wholesale price.

To answer the research questions, we need to investigate a buyer's auditing decision and the purchasing and production decisions within the supply chain. In this case, a research method based on a quantitative model is the proper method. The topic under investigation in this paper belongs to the field of operations management. Quantitative models are commonly used in the literature on operations management. The quantitative, model-based research method uses objective mathematical models that predict the behavior of real-life operational processes and capture the decision-making processes faced by managers engaged in real-life operations (Karlsson, 2016). This method is usually prescriptive, meaning that the researchers are primarily interested in developing actions, strategies, and policies to improve the situations over the existing actions, strategies, and policies presented in the literature (Karlsson, 2016).

In this paper, we use the methodological approaches of game theory and mechanism design. A game theoretic approach is used to analyze the interaction between the buyer and the supplier within the context of purchasing and production decisions. This interaction takes place in the form of interrelated decisions in the procurement contract, i.e., the buyer's decision on its order quantity and profit margin, and the supplier's decision on its wholesale price. Generally, game theory is an appropriate approach to study strategic interactions among rational decision makers (Bolt and Houba, 2006). In this case, game theory deals with problems in which there are interrelated decisions, meaning that the decisions of one decision maker influence not only its own utility and profit but also the utility and profit of the other decision makers in that situation (Myerson, 2013). By investigating the buyer's auditing efforts, we aim to study how the buyer's audits can lead to its desired outcome, i.e., to induce responsible sourcing. The mechanism design approach is the proper methodology for investigating this situation. Mechanism design can generally be viewed as the reverse engineering of the rules of games to create protocols or institutions that yield certain desired outcomes (Narahari, 2014).

To answer Question 1, we identify the infeasible (ineffective) region of a buyer's auditing mechanism. This infeasible region indicates that the auditing mechanism is not powerful enough to create the desired outcome, i.e., to induce responsible sourcing. To answer Questions 2 and 3, we identify the conditions in which increasing external auditing efforts and consumer awareness move the supply chain from the feasible region of the buyer's audits to the infeasible region. To answer Question 4, we identify the condition in which the buyer is hesitant to increase its auditing efforts, irrespective of the direct cost considerations of this increase. To answer Question 5, we design two types of buyer's auditing mechanisms. In the strong incentive compatibility (SIC) mechanism, the equilibrium condition in which the supplier is irresponsible shuts down production. In the weak incentive compatibility (WIC) mechanism, this

[2] https://www.fairfactories.org/.
[3] http://betterwork.org/.

equilibrium condition does not shut down production, but is not incentive-compatible. We present some criteria for comparing these two mechanisms, such as their costs, and their robustness with respect to some parameters.

To the best of our knowledge, this is the first paper to investigate the effects of the buyer's auditing mechanism on the purchasing and production decisions of supply chains. We show that higher auditing efforts within supply chains do not always promote responsible sourcing. We also show that the effect of consumer awareness on responsible sourcing is not straightforward and depends strongly on the buyer's auditing mechanism. If the buyer chooses the SIC auditing mechanism, consumer awareness always favors responsible sourcing. In contrast, if the buyer chooses the WIC auditing mechanism, consumer awareness always threatens responsible sourcing.

The remainder of this paper is organized as follows: Section 2 provides the theoretical background and reviews the related literature. In Section 3, we define the problem and provide notations. In Section 4, we formulate the problem. Section 5 provides the parametric analysis. Section 6 discusses the results and provide some implications for buyers and external stakeholders. Finally, Section 7 provides our conclusions and some suggestions for future research.

2. Theoretical background and literature review

This section provides the theoretical background for this research, then reviews the most relevant streams of literature (opportunistic behaviors of supply chain members, supply chain transparency, and mechanisms to implement responsible sourcing), and concludes with a discussion of research gaps.

2.1. Theoretical background

A *supply chain* consists of a network of connected firms that cooperate together to manage, control, and improve the flow of information and materials from *suppliers* who produce raw materials to final consumers who purchase finished products (Christopher, 2016). *Buyers* (retailers) play the critical role of intermediary between suppliers and consumers. This role enables them to influence the decisions made by suppliers and consumers (Macfadyen et al., 2015). In today's supply chains, suppliers producing (parts of) final products, usually called original equipment manufacturers (OEMs), are also of great importance (Lin, 2004).

In real-world supply chains, buyers and suppliers have long-term, *repeated* interactions with each other to produce final products and satisfy consumer demand (Sheth and Parvatiyar, 1995). Repeated interaction among these two parties is significant because it can generate *informal* agreements between them, which cannot be achieved by *formal*, court-enforceable contracts (Taylor and Plambeck, 2007). From economists' point of view, repeated interactions are also important because they strongly influence agents' incentives and shape market dynamics (Klein and Leffler, 1981; Li, 2014; MacLeod and Malcomson, 1998; Shapiro and Stiglitz, 1984).

In a supply chain, the buyer and the supplier make some purchasing and production decisions. The *wholesale price* is the price paid by the buyer to the supplier in exchange for delivering the final product (Hwang et al., 2018). The *retail price* is the price paid by final consumers to the buyer when they purchase the final product (Huang et al., 2013). A consumer's *willingness to pay* is the maximum retail price that he or she will pay for the product. Therefore, a consumer purchases a product if and only if the retail price of that product is less than or equal to his or her willingness to pay for it (Huang et al., 2013). Based on the supplier's and final consumers' conditions, the buyer decides on its *order quantity*, meaning that it decides how many final products to order from the supplier and bring the market. Finally, the buyer's *profit margin* is the difference between the retail price and the wholesale price of the product, indicating the buyer's profit for each product sold.

The negotiation between the buyer and the supplier plays a significant role in the purchasing and production decisions within a supply chain. The supplier actively engages in this negotiation, especially if it is a critical supplier to the buyer. Buyers require critical suppliers in many services such as sterilization, labeling, contract manufacturing, critical power, and electronic parts (Tai, 2015). The active engagement of a critical supplier in the above-mentioned negotiation means that it can influence the process of determining its wholesale price (Porter, 2008). The buyer must pay high switching costs if it abandons the negotiation with the critical supplier (Porter, 2008). Therefore, it remains in this negotiation process and consents to the active engagement of the supplier.

As stated in Section 1, *responsible sourcing* in a supply chain refers to suppliers' compliance with *environmental and social standards* (Agrawal and Lee, 2016). Apple has published these standards in the form of a code of conduct for suppliers (Apple, 2019). Some of the environmental standards outlined in this document are as follows:

- Waste management of hazardous and non-hazardous materials
- Air emission management
- Management of wastewater and stormwater
- Monitoring and reduction of noise
- Monitoring and reduction of the use of resources, such as fossil fuels, water, and hazardous materials, through recycling, reusing, substitution, and other methods.

Some of the social standards addressed in this document are as follows:

- Prevention of discrimination against workers
- Prevention of the use of underage labor
- Compliance with 60 working hours in a week
- Compliance with minimum wages and benefits for workers.

An *auditing* mechanism is generally defined as a process for obtaining pieces of evidence and evaluating them to determine whether the auditing criteria have been met (ISO, 2018). Generally, a mechanism is applied to generate certain desired outcomes. However, there may be some conditions in which a mechanism cannot generate its desired outcome, in which case the mechanism is considered *ineffective*. A mechanism may even generate unintended adverse outcomes, usually called *backfiring conditions* (Plambeck and Taylor, 2016). In today's supply chains, an auditing mechanism is commonly used to induce responsible sourcing. Researchers and activists who deal with the auditing mechanism frequently doubt the effectiveness of this mechanism. The most important backfiring condition that an auditing mechanism may generate is that it may encourage the auditees to hide their noncompliant activities. This reduces the potential of the auditing mechanism to discover noncompliance and may even lead to lower compliance efforts by auditees (Plambeck and Taylor, 2016).

However, it seems that suppliers in today's global supply chains are no longer able to hide their noncompliant activities. No one can deny that public awareness about the necessity of sustainable practices is increasing (Chen and Chen, 2017; Michelsen and de Boer, 2009; Miranda-Ackerman and Azzaro-Pantel, 2017; Phan and Baird, 2015). One result of this increased public awareness is the emergence of the *third-party assurance* phenomenon in which external stakeholders such as governmental and non-governmental organizations, labor unions, and other activists audit suspected noncompliant suppliers (Daddi et al., 2016; Gürtürk and Hahn, 2016; Park and Brorson, 2005). The increasing number of external auditors makes hiding noncompliant activities too expensive for suppliers. This is because the results of audits are usually shared. Hence, discovery by one auditor is enough to detect

noncompliant activities (Caro et al., 2018). Therefore, a supplier aiming to hide its noncompliant activities would need to exert hiding effort from many as auditors as are in the market. Most observers have concluded that today's auditing mechanisms tend to be effective at uncovering irresponsible sourcing, but there is a need to investigate whether or not these auditing mechanisms are effective at inducing responsible sourcing.

Supply chain decisions can be classified into three general categories: strategic, tactical and operational (Simchi-Levi et al., 2008). Strategic decisions affect the supply chain over long term and their updating frequency is low. Auditing decisions are strategic decisions. In the real world, audit clauses in agreements between firms specify a maximum number of audits in a period of time (Earnhart and Leonard, 2013), and some other decisions of firms, such as their order quantities, are made based on these clauses (Heese and Kemahlioglu-Ziya, 2014). This is good evidence for the strategic nature of auditing decisions. Tactical decisions, in contrast, are made every quarter or every year. They include purchasing and production decisions by buyers and suppliers (Simchi-Levi et al., 2008).

Two types of audits of a supplier should be analyzed separately: endogenous audits by buyers within the supply chain and exogenous audits by external stakeholders. Why is this separation important? External stakeholders do not participate in tactical decisions such as purchasing and production decisions as buyers do. Therefore, buyers' auditing efforts should be analyzed endogenously and their influence on the companies' tactical decisions should be investigated.

2.2. Literature on opportunistic behaviors of supply chain members

Williamson, the father of transaction cost economics, defined opportunism as pursuing self-interest with guile (Williamson, 1975). An agent in a game may behave opportunistically mainly because the other agents do not possess complete information (Heese and Kemahlioglu-Ziya, 2014). Withholding information and diluting responsibilities are some examples of opportunistic behaviors (Shi et al., 2018). In the problem presented in this study, the supplier's choice between responsible production and irresponsible production is an example of opportunistic behavior in supply chains. Therefore, it is necessary to review this stream of research.

Heese and Kemahlioglu-Ziya, (2014) studied a supply chain with one supplier and one retailer that interact under a revenue-sharing contract. The demand is stochastic and the retailer's revenues are unobservable to the supplier. Therefore, the retailer can report its revenues untruthfully. The supplier can commit to an auditing mechanism to learn about actual demand realization. The researchers found that the supplier will not commit to an auditing mechanism that eliminates the retailer's opportunistic behavior completely. In a more recent paper, Heese and Kemahlıoğlu-Ziya (2016) showed that the result is also robust when the retailer exerts sales efforts.

Chen and Baddam (2015) studied a two-stage supplier selection problem with one buyer that must choose between an ethical and an unethical supplier. The unethical supplier has lower production costs than the ethical supplier. When a supplier is chosen for the first stage, its selection for the next period will involve a competitive advantage called the *learning effect*. The learning effect decreases the supplier's cost of production in the next periods by increasing its experience and knowledge. The researchers' objective is to design optimal supplier selection strategies.

Li (2014) studied a repeated outsourcing problem with one firm that outsources its information technology activities to a supplier. The supplier will exploit the buyer's valuable information if the buyer does not protect it. However, information protection imposes some costs on the firm. In a repeated interaction, the firm would observe the supplier's opportunistic behavior and terminate outsourcing for the next periods. Therefore, the supplier makes a trade-off between short-term opportunism and long-term profits and growth opportunity. The objective of this study is to design a payment mechanism that prevents the supplier's opportunism without incurring protection costs.

Opportunistic behaviors have also been studied in the context of other supply chain issues such as new product development (Balachandran et al., 2013; Yan and Kull, 2015), category captainship collaboration (Brusset and Agrell, 2017), supplier justice (Huo et al., 2016), inventory control (Fu et al., 2016) and supply chain integration (Sinnandavar et al., 2018).

2.3. Literature on supply chain transparency

Supply chain transparency involves two main components: announcing the names of suppliers (Doorey, 2011; Laudal, 2010), and announcing sustainability conditions at suppliers' factories (Cramer, 2008). The buyer's auditing efforts enable it to announce whether or not its supplier is complying with environmental and social standards, indicating supply chain transparency. Hence, it is necessary to review this stream of research.

Chen and Slotnick (2015) studied two competitive supply chains in which one uses an ethical supplier and the other does not. The researchers analyzed the disclosure decisions of the supply chains in a Nash equilibrium structure and addressed the effects of disclosure on their market shares. They found that both supply chains disclose the nature of their sourcing when the probability of discovery of ethical violations is high enough. In addition, the researchers found that the cost of disclosure is a major concern for supply chain transparency; because of high disclosure costs for the unethical supply chain, an ethical supply chain should not disclose if its unethical rival does not disclose.

Guo et al. (2016) studied a supplier selection problem by a buyer. Similar to the problem presented by Chen and Baddam (2015), the buyer can choose between an ethical and a risky, unethical supplier. But Guo et al. (2016) segmented final consumers into two categories: socially conscious and non-socially conscious. The researchers studied a non-transparent supply chain in which consumers are not able to observe the buyer's sourcing decisions and the buyer can be dishonest about its decisions. The researchers found that more transparency does not necessarily increase sourcing from responsible suppliers. They also found that consumer punishment for irresponsible sourcing and the probability of violation always have a positive effect on responsible sourcing.

Karaer et al. (2017) studied a decision tool for supply chain transparency called Material IQ (MIQ), with which buyers and suppliers can share important data with consumers. These data include chemical ingredients in the products. The researchers found that if there is a single supplier, using MIQ will often be beneficial. In the case of supplier competition, the researchers found that using MIQ is beneficial when consumer awareness is high enough.

In their empirical analysis, Porteous et al. (2015) concluded that there is no significant relationship between transparency and a reduction in social and environmental responsibility violations in supply chains. They defined two types of measure for transparency: *monitoring* represents the ex-ante potential for noncompliance discovery, while *visibility* reflects the ex-post potential for discovery.

Chen et al. (2018) investigated the effect of a buyer's disclosure of its supplier's name and supply chain capability on the sustainability conditions of a supply chain. The researchers analyzed a model including a buyer, an NGO, and a supplier. In the first stage of the game, the capability of the supplier to provide efforts to improve sustainability conditions is discovered by the buyer and the supplier. The buyer's revealing this information and the name of the supplier is one aspect of supply chain transparency (Doorey, 2011; Laudal, 2010). In the second

stage of the game, the supplier provides its sustainability efforts while the buyer and the NGO provide auditing efforts to discover the supplier's noncompliance with sustainability standards. The researchers found that the buyer's transparency in disclosing the name of the supplier may conflict with the ultimate sustainability conditions.

Khosroshahi et al. (2019) investigated the effect of a supplier's transparency on the profits of the members of a supply chain that produces a green product. They defined the transparency of the supplier based on the supplier's published information about the environmental impact of its activities. Such transparency reduces consumers' uncertainty about the product attributes, and ultimately increases their willingness to pay for the supplier's product. The researchers found that greater transparency on the part of the supplier leads to higher equilibrium values for demand and supply chain profits.

Other studies investigated the relationship between supply chain transparency and supply chain analytics (Zhu et al., 2018), corporate social responsibility (New, 2015), and forward contracting (Arya et al., 2015).

2.4. Literature on mechanisms to implement responsible sourcing

Plambeck and Taylor (2016) studied a supply chain in which a buyer tries to induce responsible sourcing through an auditing mechanism. They considered two types of efforts by the supplier: responsibility and hiding efforts. They found that there is a backfiring condition in which more auditing efforts by the buyer leads to more hiding efforts, instead of more responsibility efforts. This is because passing the audits may be more profitable than responsible sourcing. To increase the supplier's responsibility efforts, the researchers suggested greater penalties for irresponsible activities and the discovery of hiding efforts. In addition, if there is a backfiring condition, squeezing the supplier's profit margin leads to more responsibility efforts. They also found a strategic wholesale price at which the backfiring condition never occurs.

Caro et al. (2018) studied a supply chain in which two buyers cooperate to design some newly dependent auditing mechanisms to induce responsible sourcing. Two buyers can use a *joint mechanism* in which they share auditing costs and charge a collective penalty if the supplier fails the audit. They can also use a *shared mechanism* in which they only share auditing reports. They found that supplier responsibility efforts are higher in joint and shared mechanisms compared to the situation in which buyers audit independently.

Chen and Lee (2017) investigated three mechanisms for responsible sourcing: certification, auditing, and deferred payment. The certification mechanism screens the supplier's ex-ante ethical level, while the auditing mechanism discovers the supplier's ex-post ethical violations. In a deferred payment mechanism, the buyer pays a portion of the wholesale price contingent on whether some violations are discovered. They found that these mechanisms are complementary, and their effectiveness at inducing responsible sourcing increases when used jointly.

In their empirical analysis, Porteous et al. (2015) classified responsible sourcing mechanisms into two categories: incentive mechanisms (such as supplier training, public recognition, business expansion, and price premiums) and penalty mechanisms (such as contract termination and business reduction). The researchers concluded that both types of mechanisms can contribute to responsible sourcing.

Eco-labelling is another mechanism to promote responsible sourcing (Miranda-Ackerman and Azzaro-Pantel, 2017), but consumers may face significant confusion when dealing with this mechanism. Harbaugh et al. (2011) showed that if there are several eco-labels or consumers are uncertain about the stringency of these labels, this mechanism may become counterproductive and uninformative. Castka and Corbett (2016) showed that this deficiency can be mitigated if trustworthy independent organizations accredit the eco-labels.

Orsdemir et al. (2019) argued that vertical integration of a buyer and its supplier is a proper mechanism for enhancing sustainability conditions in the supply chain. They explained the effects of the external auditing efforts of stakeholders, demand externalities, and the possibility of horizontal sourcing on the vertical integration decision in a supply chain. They found that if the demand externalities are strongly negative, the external auditing efforts create a backfiring condition. In this case, the buyer and the supplier vertically integrate under moderate auditing efforts and the sustainability conditions are enhanced. In contrast, under high auditing efforts they decide to stay unintegrated, and thus the sustainability conditions cannot be improved.

Awasthy and Hazra (2019) studied how some aspects of buyer-supplier collaboration can enhance the sustainability conditions of a supplier. They investigated two collaboration mechanisms: an *accord* mechanism in which the supplier and the buyer provide efforts jointly to enhance sustainability conditions, and an *alliance* mechanism in which the buyer pays for a portion of the supplier's investment in sustainability. They concluded that the supplier's and buyer's abilities to understand the technical procedures for implementing sustainability are important in ensuring that the above-mentioned mechanisms are optimal from the perspectives of the supplier, the buyer, and sustainability conditions.

2.5. Research gaps

The literature review indicates that no study has focused on how a buyer's auditing mechanism affects the production and purchasing decisions of the supply chain. Specifically, the active engagement of a critical supplier in influencing the negotiation process to determine the wholesale price should be considered when analyzing auditing mechanisms. For example, Li (2014) and Plambeck and Taylor (2016) sought to identify how the buyer can determine strategic wholesale prices that will mitigate the supplier's opportunism and enhance its responsibility efforts. However, critical suppliers may not consent to such strategic wholesale prices because of their active engagement in the wholesale price determination. Also, internal audits by buyers should be distinguished from external audits by external stakeholders. External stakeholders do not participate in the purchasing and production decisions within the supply chain, but the buyers do. Therefore, buyers' auditing efforts should be analyzed endogenously. Their influence on the production and purchasing decisions should also be investigated. To the best of our knowledge, no study has addressed these issues.

To the best of our knowledge, no study has investigated the long-term effects of auditing mechanisms in supply chains. Generally, the recent literature on sustainable supply chain management suggests the development of governance mechanisms that provide long-term incentives for agents to act in a sustainable manner (Reefke and Sundaram, 2017). In this case, the study of repeated interactions between the buyer and the supplier helps us develop auditing mechanisms and provide these long-term incentives for buyers and suppliers.

Internal and external auditing efforts in a supply chain may generate some backfiring conditions, i.e., they may generate some adverse effects on sustainability conditions. For example, high external auditing efforts by NGOs may deter the buyer and the supplier from becoming vertically integrated, and consequently may be detrimental to sustainability conditions (Orsdemir et al., 2019). Also, a buyer's internal audits within a supply chain may generate a backfiring condition because the audits may encourage the supplier's hiding effort. Such hiding efforts reduce the potential of the audits to discover noncompliance and may even lead to lower compliance efforts by the supplier (Plambeck and Taylor, 2016). It is important to explore other backfiring conditions for supply chain audits. This analysis will help managers of supply chains increase their knowledge about auditing mechanisms, which ultimately contributes to sustainability conditions within supply chains.

Finally, there is a need to deeply investigate the relationship between supply chain transparency and sustainability conditions. Chen et al. (2018) recently found that the buyer's transparency in disclosing the name of its supplier may conflict with responsible sourcing. However, to the best of our knowledge, no study exists that investigates how the buyer's disclosure of sustainability conditions at supplier factories interacts with responsible sourcing. This investigation suggests some implications for anti-sweatshop campaigns and whether or not to encourage buyers to increase their transparency.

3. Problem definition

This section provides the problem definition in two subsections. Section 3.1 describes the problem, and Section 3.2 provides the notations.

3.1. Problem description

This paper studies a supply chain that consists of one buyer, one critical supplier, and final consumers. As in the real world, the buyer and supplier have repeated interactions in which the buyer gives the supplier some orders to produce the product in an infinite number of tactical periods.

Similar to the literature on "take it or leave it" offers in supply chains (Chen and Lee, 2017; Won, 2017), the minimum attractive rate of return (outside option) is zero within each tactical period; therefore, the related discount rate is equal to 1. This is because the duration of a period is short, at less than one year. Suppose that a decision influences the profits of the agents for only one period. This decision must be analyzed using the zero outside option and the decision maker must optimize its short-term profits because its decision does not influence the profits of the following periods. However, as indicated in the literature on repeated game theory (Osborne, 2004), the discount rate between two consecutive periods is equal to δ. Suppose that a decision influences the profits of the agents not only for that period but also the profits for the following periods. This decision must be analyzed using the discount rate of δ and the decision maker must optimize its long-term profits.

In each period, the buyer and the supplier need a procurement contract for making purchasing and production decisions. A wholesale price contract is typically used for this purpose; this contract is widely applied in the real world and in academic studies. It includes two stages (Hwang et al., 2018): in the first stage, the buyer and the supplier negotiate for the supplier's wholesale price in order to reach an equilibrium value for it. In the second stage, the buyer determines the order quantity. The negotiation is modeled as a game in which the supplier determines the wholesale price while the buyer also competes with the supplier for its profit margin. This approach is similar to that seen in some of the literature on wholesale price contracts (Choi, 1991; Dai et al., 2018; Ma et al., 2017) in which the buyer (retailer) competes for its profit margin (m) and tries to commit itself to the profit margin in the next stage. It is also consistent with real-world observations in which buyers try to pledge a specified rate of return to their investors.

As in Chen and Baddam (2015), the buyer's products are sold in a Cournot market in which the price is inversely related to the quantity sold. Also, as in Chen and Lee (2017), the supplier has two choices when determining the production process: a responsible (ethical) choice that imposes a production cost of c_E, and an irresponsible (unethical) choice that imposes a production cost of c_U ($c_U < c_E$). The supplier's decision regarding the type of production is invisible unless a process such as auditing is used to uncover this decision.

In each period, the market discovers irresponsible production with the probability of θ. Two different types of events may influence this probability (Chen and Lee, 2017). The first type is occurrence of a crisis in the supplier's factories, such as fire. The second type is the auditing efforts conducted by activists outside the supply chain, such as governments, NGOs, and labor unions. As in Chen and Baddam, 2015; Chen and Slotnick, 2015, the buyer and supplier will not face legal action if the supplier does not produce responsibly; several real-world pieces of evidence from emerging economies suggest that labor laws have not improved labor conditions, neither at enactment nor through enforcement.[4] Instead, in the case of discovery of irresponsible production, consumers punish the buying firm by reducing their willingness-to-pay (Chen and Baddam, 2015; Trudel and Cotte, 2009). The severity of this punishment is related to their environmental and social awareness.

For financial and reputational reasons, the buyer seeks responsible sourcing. The supplier is the buyer's critical supplier. Therefore, the process of switching to a responsible supplier will be very costly if the supplier does not comply with responsible production standards. This problem stimulates the buyer to use an auditing mechanism to induce the supplier to produce responsibly. The buyer seeks optimal auditing efforts that maximize its profit under responsible sourcing. Violation of responsible production standards will be detected by the buyer's auditing efforts or the discovery by the market. The buyer announces credibly and publicly that it will terminate sourcing from the supplier in the event of discovery of irresponsible production. This announcement protects the buyer's future reputation and profits. The buyer announces the probability of audit per period (γ). This probability is also equivalent to the average time between two successive audits. For example, $\gamma = 0.25$ means that the average time is four periods. This type of announcement is practical in the real world. For example, audit clauses in agreements between firms specify and announce a maximum number of audits in a period of time (Heese and Kemahlioglu-Ziya, 2014).

As in Chen and Slotnick (2015), the total cost of auditing is linearly dependent on the quantity of products produced. This seems reasonable because many auditing processes depend on the volume of production. For example, interviewing with a sample of employees to discover working conditions is a common and important process in auditing for responsible sourcing (Egels-Zandén, 2007).

Fig. 1 depicts the timeline of the model.

At the strategic level, the buyer announces the level of its expected auditing efforts. Two factors determine these efforts. First, the level of the efforts is determined so that it can induce responsible sourcing. Second, it is determined so that it is cost efficient. Therefore, the supplier determines its auditing efforts to maximize its long-term profit while inducing responsible sourcing. In stages 1 and 2 of each selling (tactical) period, the buyer and the supplier compete with each other while creating a wholesale price contract. Competition in this contract means that each decision maker is concerned with only its own profit. Stage 3 in each tactical period is the production stage, when the supplier decides whether or not to produce the products responsibly. If the supplier decides on responsible production, the supplier's relationship with the buyer will continue in the next stages. In contrast, if the supplier decides on irresponsible production, the relationship may be terminated. This termination will take place if an audit is conducted after production (stage 4) and the audit discovers the irresponsible production. In addition to the termination of the supplier for the following tactical periods, consumers will punish the buyer by reducing their willingness to pay (stage 5).

[4] Caro et al. (2018) point out that international buyers are not *legally* responsible for safety conditions at their supplier's manufacturing plants. Plambeck and Taylor (2016) believe that the expected punishment for irresponsible sourcing is negligible in China because regulators do not possess sufficient resources and concentrate on economic growth. Economist (2017) believes that the lack of genuine bargaining and independent labor unions leaves China's blue-collar laborers dissatisfied and vulnerable. Pei-Ju (2017) reports on a protest by Taiwanese labors and citizens in which they believed that a new revision of the labor law would undermine the rights of workers and worsen working conditions. Bulletin (2018), in describing the condition of the Labour Contract Law in China, points out that local governments enforce the law selectively and businesses exploit loopholes.

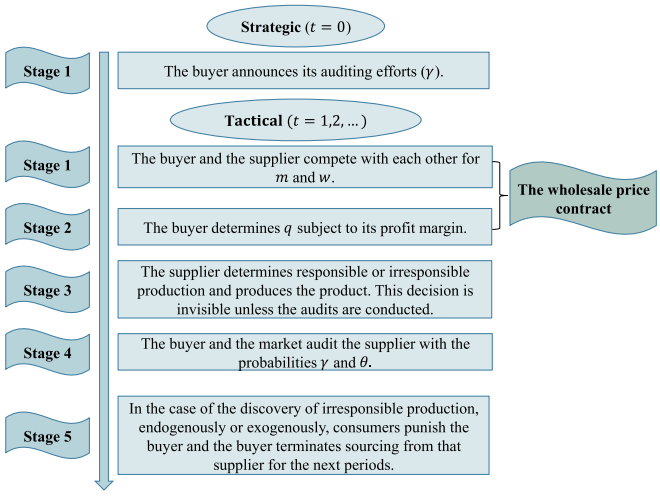

Fig. 1. The timeline of the problem.

3.2. Notations

Subscripts	
$i = B$	The buyer
$i = S$	The supplier
$y = E$	Responsible sourcing
$y = U$	Irresponsible sourcing
Superscripts	
$j = S$	Equilibrium values under strong incentive compatibility
$j = W$	Equilibrium values under weak incentive compatibility
BR	Best response
Parameters	
δ	The discount rate between two consecutive tactical periods $(0 \le \delta < 1)$
c_a	The unit cost of auditing $(c_a > 0)$
k	The leniency of the market response to irresponsible production $(0 \le k \le 1)$
θ	The market probability of discovery of irresponsible production $(0 \le \theta \le 1)$
c_y	The supplier's unit cost of production when it chooses y $(0 < c_U < c_E < 1)$
Decision variables	
γ	The probability of audit by the buyer for each period $(0 \le \gamma \le 1)$
m	The buyer's profit margin $(m \ge 0)$
w	The wholesale price of the product $(\forall y: w_y \ge c_y)$
q	The quantity of production per period $(q \ge 0)$
Dependent variables	
ϕ	The total probability of discovery per period for the supplier's irresponsible production
p	The market price of the product
$\tilde{\gamma}$	The minimum probability of audit for each period that induces responsible production
$\pi_{i,y}$	Player i's profit per period when the supplier chooses y
$\Pi_{i,y}$	Player i's expected present value of profit when the supplier chooses y

4. Model formulation

This section formulates the problem and solves it. We follow backward induction in which decision makers at higher stages of the problem predict rational expectations for the decisions made at lower stages.

4.1. The supplier's choice between responsible and irresponsible sourcing

First, the total probability of discovery contingent on irresponsible sourcing is calculated. According to the arguments presented in Section 1, auditing mechanisms are effective at discovering irresponsible sourcing in today's supply chains. Therefore, the probability of audit is equal to the probability of discovery. Consumers do not discover the irresponsible behavior if the market and the buyer do not audit the supplier; ϕ is calculated as follows:

$$\phi = 1 - (1-\gamma)(1-\theta) \tag{1}$$

In this stage, the values of w and q are considered as a parameter. For the construction of $\pi_{S,y}$, the rational expectation of the supplier about q in the next periods is used; because common knowledge tends to be fixed in all periods, the supplier expects that q will be fixed in all periods. This approach is similarly applied in the work of Heese and Kemahlıoğlu-Ziya (2016). Therefore, the supplier's profit for one period is as follows:

$$\pi_{S,y} = (w - c_y)q \tag{2}$$

For the construction of $\Pi_{S,y}$, Proposition 1 is used. **All proofs have been provided in the online appendix.**

Proposition 1. *For responsible sourcing, the conditions $w > c_E$ and $q > 0$ must be satisfied. In addition, under this condition, the values of $\Pi_{S,E}$ and $\Pi_{S,U}$ are as follows:*

$$\Pi_{S,E} = \frac{(w - c_E)q}{1 - \delta} \tag{3}$$

$$\Pi_{S,U} = \frac{(w - c_U)q}{1 - (1-\phi)\delta} = \frac{(w - c_U)q}{1 - (1-\gamma)(1-\theta)\delta} \tag{4}$$

The supplier will always choose responsible production if this choice provides it with a greater expected present value of profit. Therefore, the incentive compatibility condition for responsible production is as follows:

$$\Pi_{S,E} \ge \Pi_{S,U} \Leftrightarrow \frac{1 - (1-\gamma)(1-\theta)\delta}{1 - \delta} \ge \frac{w - c_U}{w - c_E} \tag{5}$$

Relation (5) can be rewritten by the buyer's auditing efforts γ:

$$\gamma \ge 1 - \frac{w\delta - c_E + (1-\delta)c_U}{\delta(1-\theta)(w - c_E)} \equiv \tilde{\gamma}(w) \tag{6}$$

Corollary 1. *$\tilde{\gamma}$ is decreasing in w:*

$$\frac{\delta\tilde{\gamma}}{\delta w} = -\frac{(1-\delta)(c_E - c_U)}{\delta(1-\theta)(w - c_E)^2} < 0 \tag{7}$$

Corollary 1 indicates that suppliers with higher wholesale prices are less willing to participate in irresponsible sourcing. This is because the minimum required auditing efforts for inducing responsible sourcing is decreasing in the wholesale price.

4.2. The buyer's quantity decision

As in Chen and Baddam (2015) and without loss of generality, the maximum market size and consumer willingness to pay are normalized to 1 and $[0, 1]$ respectively. Therefore, when both players anticipate a responsible sourcing equilibrium, the price demanded by consumers will be equal to:

$$p_E = 1 - q_E \tag{8}$$

According to Equation (8), the best response for the buyer's quantity decision under the responsible sourcing equilibrium is as follows:

$$m_E = 1 - q_E - w_E - c_a\gamma \Rightarrow q_E = 1 - (w_E + m_E + c_a\gamma), q_E \ge 0$$

$$\Rightarrow q_E^{BR} = Max\{1 - (w_E + m_E + c_a\gamma), 0\} \tag{9}$$

As mentioned in Section 3, consumers will punish the buyer by reducing their willingness to pay if they discover irresponsible sourcing. As in Chen and Baddam (2015), the price will be equal to $k(1-q)$ if the

irresponsible sourcing is discovered. Therefore, the expected value of the price is equal to:

$$p_U = \phi k(1-q_U) + (1-\phi)(1-q_U) = (1-q_U)(1+\phi(k-1))$$

$$= (1-q_U)(1+(k-1)(\theta+(1-\theta)\gamma)) \quad (10)$$

The best response for the buyer's quantity decision under the irresponsible sourcing equilibrium is as follows:

$$m_U = (1-q_U)(1+(k-1)(\theta+(1-\theta)\gamma)) - w_U - c_a\gamma, q_U \geq 0$$

$$\Rightarrow q_U^{BR} = Max\left\{1 - \frac{m_U + w_U + c_a\gamma}{1+(k-1)(\theta+(1-\theta)\gamma)}, 0\right\} \quad (11)$$

4.3. The competition to determine the buyer's profit margin and the supplier's wholesale price

According to Relations (9) and (11), the players' profits for one period under the responsible and irresponsible sourcing equilibria are as follows:

$$\pi_{B,E}(m_E, w_E) = m_E q_E = m_E(1-(w_E + m_E + c_a\gamma)) \quad (12)$$

$$\pi_{S,E}(m_E, w_E) = (w_E - c_E)q_E = (w_E - c_E)(1-(w_E + m_E + c_a\gamma)) \quad (13)$$

$$\pi_{B,U}(m_U, w_U) = m_U q_U = m_U\left(1 - \frac{m_U + w_U + c_a\gamma}{1+(k-1)(\theta+(1-\theta)\gamma)}\right) \quad (14)$$

$$\pi_{S,U}(m_U, w_U) = (w_U - c_U)q_U = (w_E - c_E)\left(1 - \frac{m_U + w_U + c_a\gamma}{1+(k-1)(\theta+(1-\theta)\gamma)}\right) \quad (15)$$

The Nash equilibria of the competition under the responsible and irresponsible sourcing equilibria are as follows:

Proposition 2. *The competition between the supplier and the buyer*

1. *Under the responsible sourcing equilibrium, the equilibrium values for m_E, w_E, q_E and $\pi_{i,E}$ are as follows*:

$$m_E^* = q_E^* = Max\left\{\frac{1}{3}(1-c_E-c_a\gamma), 0\right\} \quad (16)$$

$$w_E^* = Max\left\{\frac{1}{3}(1+2c_E-c_a\gamma), c_E\right\} \quad (17)$$

$$\pi_{B,E}^*(\gamma) = \pi_{S,E}^*(\gamma) = \frac{1}{9}(Max\{1-c_E-c_a\gamma, 0\})^2 \quad (18)$$

2. *Under the irresponsible sourcing equilibrium, the equilibrium values for m_U, w_U, q_U and $\pi_{i,U}$ are as follows*:

$$m_U^* = q_U^* = Max\left\{\frac{1}{3}(1+(k-1)(\theta+(1-\theta)\gamma) - c_U - c_a\gamma), 0\right\} \quad (19)$$

$$w_U^* = Max\left\{\frac{1}{3}(1+(k-1)(\theta+(1-\theta)\gamma) + 2c_U - c_a\gamma), c_U\right\} \quad (20)$$

$$\pi_{B,U}^*(\gamma) = \pi_{S,U}^*(\gamma) = \frac{(Max\{1+(k-1)(\theta+(1-\theta)\gamma) - c_U - c_a\gamma, 0\})^2}{9(1+(k-1)(\theta+(1-\theta)\gamma))} \quad (21)$$

In Corollary 2, three conditions for the shutting down of production are investigated for each equilibrium. Corollary 3 indicates that the supplier requires an efficiency wage for responsible production.

Corollary 2. *The buyer and the supplier shut down the production if they face negatively expected profit margin or a negative quantity of production. For every equilibrium y, the three conditions for the shutting down of production, i.e., $m_y^* = 0$, $w_y^* = c_y$, and $q_y^* = 0$, are all equivalent:*

Table 1
The characteristics of the SIC problem.

Condition number	Details	Mathematical expression
1	The responsible sourcing equilibrium does not shut down production.	$1 - c_E - c_a\gamma \geq 0$
2	In the responsible sourcing equilibrium, the supplier has no incentive to violate responsible sourcing standards.	$\gamma \geq \bar{\gamma}(w_E^*)$
3	The irresponsible sourcing equilibrium shuts down production.	$1+(k-1)(\theta+(1-\theta)\gamma) - c_U - c_a\gamma \leq 0$

$$m_E^* = 0, w_E^* = c_E, q_E^* = 0 \Leftrightarrow 1 - c_E - c_a\gamma \leq 0 \quad (22)$$

$$m_U^* = 0, w_U^* = c_U, q_U^* = 0 \Leftrightarrow 1+(k-1)(\theta+(1-\theta)\gamma) - c_U - c_a\gamma \leq 0 \quad (23)$$

Corollary 3. *If the two equilibria lead to production, the efficiency wage allocated to the responsible supplier is as follows:*

$$w_E^* - w_U^* = \frac{1}{3}(2(c_E - c_U) + (1-k)(\theta+(1-\theta)\gamma)) > 0 \quad (24)$$

The result of Corollary 3 is available in the literature. For example, Chen and Lee (2017) point out that suppliers with higher degrees of responsibility require higher minimum wholesale prices. The difference between our work and the research presented in the literature is that we show that this result is robust when suppliers have pricing power and the quantity and retail price of the product are determined endogenously.

4.4. The buyer's auditing mechanism

This section analyzes the buyer's auditing mechanism and investigates how the buyer's auditing efforts provide conditions in which the agents tend to choose only the responsible sourcing equilibrium. In this setting, the buyer and supplier always decide according to the responsible sourcing equilibrium and anticipate that the other agent will do as well. Two types of incentive compatible mechanisms are defined: strong incentive compatibility (SIC) and weak incentive compatibility (WIC). From a technical point of view, these two mechanisms belongs to dominant-strategy incentive compatible mechanisms because the responsible sourcing equilibrium is the only Nash equilibrium in the problem. For more information about dominant-strategy incentive compatible mechanisms, please see: Narahari (2014), pages 227, 240, and 241.

4.4.1. The SIC problem

In the SIC problem, the buyer determines its auditing efforts so that an irresponsible sourcing equilibrium leads to the shutting down of production and the responsible sourcing equilibrium leads to responsible production. In this case, the agents do not choose the irresponsible sourcing equilibrium because it does not provide a positive profit. In contrast, the responsible sourcing equilibrium provides a positive profit for them and is incentive-compatible. These conditions are constructed in Table 1 according to Relation (6) and Corollary 2.

Proposition 3. *The buyer's optimal auditing efforts under the SIC problem are as follows*[5]*:*

[5] The definitions of new expressions in the paper are presented in the Appendix.

$$\gamma^S = Max\left\{0, \frac{-\delta A_1 - \sqrt{\delta^2 {A_1}^2 - 12\delta c_a(1-\theta)A_2}}{6\delta(1-\theta)c_a}, \frac{1-c_U-(1-k)\theta}{c_a+(1-k)(1-\theta)}\right\} \tag{25}$$

In addition, the SIC problem is feasible if and only if both of the following conditions hold:

$$\delta^2 {A_1}^2 - 12\delta c_a(1-\theta)A_2 \geq 0 \tag{26}$$

$$Max\left\{0, \frac{-\delta A_1 - \sqrt{\delta^2 {A_1}^2 - 12\delta c_a(1-\theta)A_2}}{6\delta(1-\theta)c_a}, \frac{1-c_U-(1-k)\theta}{c_a+(1-k)(1-\theta)}\right\} \leq Min\left\{1, \frac{-\delta A_1 + \sqrt{\delta^2 {A_1}^2 - 12\delta c_a(1-\theta)A_2}}{6\delta(1-\theta)c_a}, \frac{1-c_E}{c_a}\right\} \tag{27}$$

4.4.2. The WIC problem

In the WIC problem, the buyer determines its auditing efforts so that both irresponsible and responsible sourcing equilibria lead to responsible production. In this case, the agents do not choose the irresponsible sourcing equilibrium because it is not incentive-compatible and does not lead to irresponsible production. These conditions are constructed in Table 2 according to Relation (6) and Corollaries 1–3.

How can we interpret condition 4 in Table 2? Why do the values of w_U^* in the interval of $[c_U, c_E)$ not provide sufficient incentive for the agents to choose only the responsible sourcing equilibrium? If w_U^* fell into this interval, then the irresponsible sourcing equilibrium would also be incentive-compatible and might be chosen by the agents because of the shutting down of production by the responsible sourcing equilibrium. In contrast, for the values of w_U^* more than c_E, the supplier has an incentive to move from irresponsible production to responsible production because the responsible sourcing equilibrium does not shut down production and all the agents can gain a positive profit.

Proposition 4. *The buyer's optimal auditing efforts under the WIC problem are as follows:*

$$\gamma^W = Max\left\{0, \frac{-\delta A_3 - \sqrt{\delta^2 {A_3}^2 + 2\delta A_4 A_5}}{\delta A_5}\right\} \tag{28}$$

In addition, the WIC problem is feasible if and only if both of the following conditions hold:

$$\delta^2 {A_3}^2 + 2\delta A_4 A_5 \geq 0 \tag{29}$$

$$Max\left\{0, \frac{-\delta A_3 - \sqrt{\delta^2 {A_3}^2 + 2\delta A_4 A_5}}{\delta A_5}\right\} \leq Min\left\{1, \frac{-\delta A_3 + \sqrt{\delta^2 {A_3}^2 + 2\delta A_4 A_5}}{\delta A_5}, \frac{1+2c_U-\theta(1-k)-3c_E}{c_a+(1-\theta)(1-k)}\right\} \tag{30}$$

Table 2
The characteristics of the WIC problem.

Condition number	Details	Mathematical expression
1	The responsible sourcing equilibrium does not shut down production.	$1 - c_E - c_a\gamma \geq 0$
2	In the responsible sourcing equilibrium, the supplier has no incentive to violate responsible sourcing standards.	$\gamma \geq \tilde{\gamma}(w_E^*)$
3	The irresponsible sourcing equilibrium does not shut down production.	$1 + (k-1)(\theta + (1-\theta)\gamma) - c_U - c_a\gamma \geq 0$
4	In the irresponsible sourcing equilibrium, the supplier has an incentive to move from irresponsible production to responsible production.	$w_U^* \geq c_E$, $\gamma \geq \tilde{\gamma}(w_U^*)$

Corollary 4 explains how we entitled the problems. It states that if both problems are feasible, the SIC problem uses more (stronger) optimal auditing efforts compared to the WIC problem.

Corollary 4. *If both problems are feasible, then the SIC problem incurs more optimal auditing efforts compared to the WIC problem:*

$$\gamma^S \geq \gamma^W \tag{31}$$

The buyer may not be able to determine its auditing efforts unilaterally. As stated in Section 1, anti-sweatshop campaigns may force the buyer to increase its auditing efforts (transparency). How does this pressure affect responsible sourcing? Corollary 5 indicates that the buyer's auditing mechanism may have a backfiring condition: higher auditing efforts may eliminate the supplier's incentive for responsible production. According to Equation (16), this is because higher auditing efforts reduce the supplier's wholesale price. Lower wholesale prices will offset the greater potential for discovery if the auditing mechanism faces a backfiring condition.

Corollary 5. *Endogenous backfiring conditions*

The SIC problem will face an endogenous backfiring condition if and only if it is feasible and the following condition holds:

$$A_6 < 1 \tag{32}$$

In this case, auditing efforts in the interval of $[\gamma^S, A_6]$ lead to responsible sourcing, but those in the interval of $(A_6, 1]$ do not.

The WIC problem will face an endogenous backfiring condition if and only if it is feasible and the following condition holds:

$$A_7 < 1 \tag{33}$$

In this case, auditing efforts in the interval of $[\gamma^W, A_7]$ lead to responsible sourcing, but those in the interval of $(A_{7,1}]$ do not.

5. Parametric analysis

This section provides some analyses to expand our knowledge about the SIC and WIC problems. First, Section 5.1 provides some tractable conditions for the auditing mechanisms to be ineffective to induce responsible sourcing. Then, Sections 5.2 and 5.3 investigate endogenous and exogenous backfiring conditions and provide some tractable conditions for them. Finally, Section 5.4 presents some numerical examples.

5.1. Sufficient conditions for the buyer's auditing mechanisms not to be effective

In this section, Propositions 5 and 6 provide some tractable conditions for auditing mechanisms to be ineffective.

Propositions 5. *Some sufficient conditions for the SIC problem not to be feasible.*

The SIC problem will not be feasible if one of the following holds:

- $Min\{\widehat{c}_1, \widehat{c}_2\} < c_E - c_U \leq 1$.
- $\theta \leq \frac{2}{3}$ & $0 < c_E - c_U \leq Min\{\widehat{c}_1, \widehat{c}_2\}$ & $c_a > \frac{3(1-c_E)(1-\theta)}{2-3\theta}$.
- $\widehat{k}_1 < k \leq 1$.

Propositions 6. *Some sufficient conditions for the WIC problem not to be feasible.*

The WIC problem will not be feasible if one of the following holds:

- $0 \le k < \widehat{k}_2$.
- $Max\{\widehat{k}_2, \widehat{k}_3\} \langle k \le 1 \ \ \& \ \ \widehat{c}_3 < c_E - c_U < 1$.
- $\widehat{k}_2 \le k \le 1 \ \ \& \ \ Min\{\widehat{c}_6, Max\{\widehat{c}_4, \widehat{c}_5\}\} \ \ < c_E - c_U < 1$.
- $\widehat{\theta}_1 < \theta \le 1$.

According to Propositions 5 and 6, consumer awareness plays an important role in SIC and WIC feasibility. Higher consumer awareness is equivalent to lower values of the parameter k. According to Propositions 5 and 6, the SIC (WIC) problem is feasible under high (low) consumer awareness. This difference between the two problems originates from their different behaviors with regard to the irresponsible sourcing equilibrium. According to Tables 1 and 2, the SIC problem holds w_U^* lower than c_U, while the WIC problem sets it higher than c_E. The first derivative of w_U^* with respect to γ is equal to:

$$\frac{\partial w_U^*}{\partial \gamma} = -(1-k)(1-\theta) \tag{34}$$

According to Equation (34), w_U^* can be reduced to c_U with even low values of γ if k is low enough and high values of γ also hold w_U^* lower than c_U. Therefore, high consumer awareness may be a necessary component for SIC feasibility. However, in order for w_U^* to be higher than c_E under a wide range for the variable γ that meets the other requirements of the WIC problem, the value of the parameter k must be high enough. Therefore, low consumer awareness may be a necessary component for WIC feasibility.

5.2. Analysis of endogenous backfiring conditions

This section investigates endogenous backfiring condition for auditing mechanisms. According to Proposition 7, the unit cost of auditing is an important parameter for the endogenous backfiring condition of the SIC problem.

Propositions 7. *Endogenous backfiring condition for the SIC problem*

- *The parameter k is irrelevant to the endogenous backfiring condition for the SIC problem.*

A feasible SIC problem will never face an endogenous backfiring condition if one of the following holds:

- $0 \le c_a \le \frac{3(1-c_E)(1-\theta)}{4-3\theta}$.
- $\frac{3(1-c_E)(1-\theta)}{4-3\theta} < c_a \le 1 - c_E$ *and* $\widehat{\delta}_1 \le \delta < 1$.

A feasible SIC problem will always face an endogenous backfiring condition if one of the following holds:

- $c_a > 1 - c_E$.
- $\frac{3(1-c_E)(1-\theta)}{4-3\theta} < c_a \le 1 - c_E$ *and* $0 \le \delta < \widehat{\delta}_1$.

In addition, $0 < \widehat{\delta}_1 < 1$ *holds.*

According to Proposition 8, the unit cost of auditing and consumer awareness are two important parameters for the endogenous backfiring condition of the WIC problem.

Propositions 8. *Endogenous backfiring condition for the WIC problem*

A feasible WIC problem will never face an endogenous backfiring condition if the following holds:

- $0 \le c_a \le Min\{\widehat{c}_{a1}, \ \widehat{c}_{a2}\}$.

A feasible WIC problem will always face an endogenous backfiring condition if the following holds:

- $c_a > Min\{\widehat{c}_{a1}, Max\{\widehat{c}_{a2}, \widehat{c}_{a3}\}\}$.

$\widehat{c}_{a1}$, $\widehat{c}_{a2}$ and $\widehat{c}_{a3}$ are increasing in k. Therefore, a decrease in the value of k may push WIC problem toward the endogenous backfiring condition. In addition, an increase in the value of k may rescue WIC problem from the endogenous backfiring condition.

5.3. Analysis of exogenous backfiring conditions

This section investigates the exogenous backfiring condition for auditing mechanisms. When there is an exogenous backfiring condition, lower auditing efforts of external stakeholders lead to responsible sourcing, but higher ones do not generate incentives for responsible sourcing, from the perspective of that incentive compatibility problem.

Propositions 9. *Exogenous backfiring conditions*

- *The SIC problem never faces an exogenous backfiring condition.*
- *If* $0 < 1 - c_U - 3(c_E - c_U) < 1 - k$ *holds and there exists at least one* θ *in the interval of* $[0, \widehat{\theta}_1]$ *in which the WIC problem is feasible, then the WIC problem will face an exogenous backfiring condition.*

The difference between the SIC and WIC problems with respect to exogenous backfiring condition originates from their different behaviors with regard to the irresponsible sourcing equilibrium. According to Tables 1 and 2, the SIC problem holds w_U^* lower than c_U, while the WIC problem sets it higher than c_E. The first derivative of w_U^* with respect to θ is equal to:

$$\frac{\partial w_U^*}{\partial \theta} = -(1-k)(1-\gamma) \tag{35}$$

Consider the WIC problem and suppose that the θ parameter has increased. According to Equation (35), w_U^* may be reduced to c_E because of this increase. In addition, the WIC problem cannot benefit from this increase in the discovery of noncompliance and cannot reduce the variable γ because this reduction accelerates the reduction in the value of w_U^*. In contrast, the SIC problem benefits from the increase in the value of θ and the buyer can freely decrease its auditing efforts.

5.4. Numerical examples

In this section, we provide some numerical analyses. In Section 5.4.1, we show that how our models can make successful predication for a situation in the real world. In Section 5.4.2, we show the endogenous backfiring conditions of the WIC and SIC problems. In Section 5.4.3, we show that there is no general relationship between the feasibility of the SIC and WIC problems.

5.4.1. A test of the models with a situation in the real world

In this section, we use some real data to investigate whether or not the auditing mechanisms are effective to induce responsible sourcing. In the work of Chen and Slotnick (2015), the researchers studied a situation in which two supply chains exist, one with a responsible supplier and the other with an irresponsible supplier. We show that our analyses can accurately predict the existence of these two types of supply chains.

The following value for the parameters and variables are provided in the work of Chen and Slotnick (2015) (page 23): $p_E = 1$, $q_E = 0.4$, $c_E = 0.25$, $c_U = 0.1$, $c_a = 0.2$, $\theta \in \{0.65, 0.9\}$. The population of the market is normalized in the data. However, the consumers' maximum willingness to pay requires to be normalized to one, and the unit costs must be modified according to this normalization. According to Equation (8) and with $q_E = 0.4$, the normalized retail price is $p_E(normalized) = 1 - q_E = 0.6$. Since $p_E = 1$, we conclude that all values of c_E, c_U , and c_a must be multiplied by $0.6 = \frac{p_E(normalized)}{p_E} = 0.6$. Therefore, we have:

$$c_E = 0.15,\ c_U = 0.06, c_a = 0.12 \tag{36}$$

For estimating the value of δ, we can use the annual interest rate of China, the place of many suppliers. According to (Economics, 2019), the annual interest rate r is equal to 4.35%. According to Osborne, 2004, the following relation holds for r and δ:

$$\delta = \frac{1}{1+r} \tag{37}$$

Therefore, $\delta = \frac{1}{1.0435} = 0.9583$. Finally, for estimating the responses of consumers with regard to the discovery of irresponsible sourcing, a questionnaire can be used. For example, a survey conducted by Trudel and Cotte (2009) (page 66) showed that the average consumers' willingness to pay for unethically-produced products is about 18% lower than ethically-produced products ($k = 1 - 0.18 = 0.82$). Table 3 and Figs. 2 and 3 show the results of the SIC and WIC problems.

According to Table 3 and Figs. 2 and 3, the WIC problem is feasible and the buyer's optimal auditing effort under the WIC problem is equal to zero. We conclude that even the external auditing efforts are sufficient for inducing responsible sourcing in the real-world situation characterized by Chen and Slotnick (2015). Therefore, we anticipate that supply chains with responsible suppliers exist in the situation. In contrast, the SIC problem is infeasible. Therefore, neither the external auditing efforts nor the combination of internal and external auditing efforts can provide great incentive for buyers to completely eliminate irresponsible suppliers. Given some practical burdens to completely implement responsible sourcing in some supply chains,[6] our models predict that irresponsible suppliers may exist in the situation characterized by Chen and Slotnick (2015). However, our analyses suggest that if such burdens are resolved, all supply chains will have sufficient incentives to comply with the responsible sourcing standards.

5.4.2. Analysis of the SIC and WIC problems with respect to the buyer's auditing efforts and the parameters

This section investigates the SIC and WIC problems with respect to the buyer's auditing efforts (γ) and each parameter. The purpose is to show four regions:

- Incentive compatibility problem infeasibility in which no auditing effort leads to responsible sourcing
- Incentive compatibility problem with an endogenous backfiring condition in which the present auditing efforts do not lead to responsible sourcing but lower ones do

Table 3
The result of the models for some real data.

The value of θ (the probablity of external audits)	γ^W(the buyer's optimal auditing effort in the WIC problem)	γ^S(the buyer's optimal auditing effort in the SIC problem)
$\theta = 0.65$	0	N/A (the SIC problem is ineffective to induce responsible sourcing).
$\theta = 0.9$	0	N/A (the SIC problem is ineffective to induce responsible sourcing).

[6] For example, Chen and Baddam (2015) point out that for some minerals, the supply of conflict-free smelters is not as sufficient as the needs of large buyers such as Motorola and Samsung are completely satisfied. As another practical burden, certified and non-certified minerals may be mixed in the factories of some suppliers (van den Brink et al., 2019). Therefore, there is no completely conflict-free mineral in supply chains.

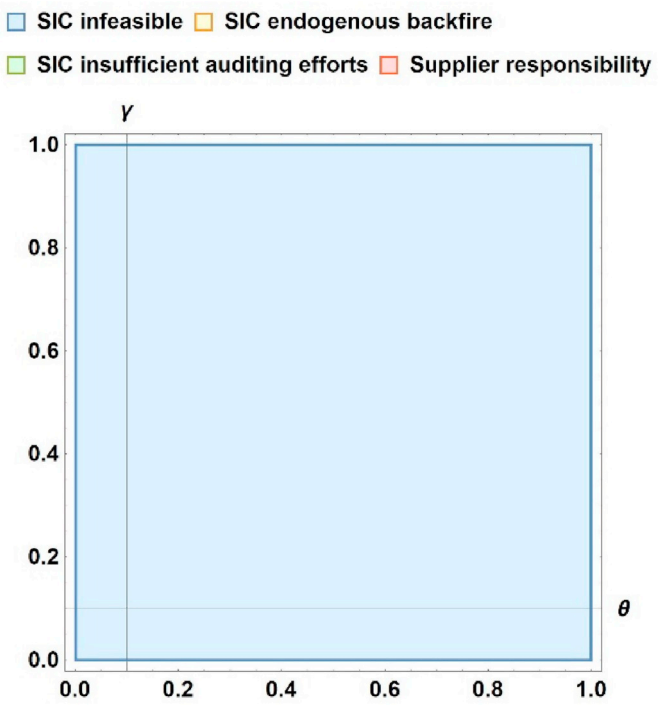

Fig. 2. Analysis of the SIC problem with respect to γ and θ

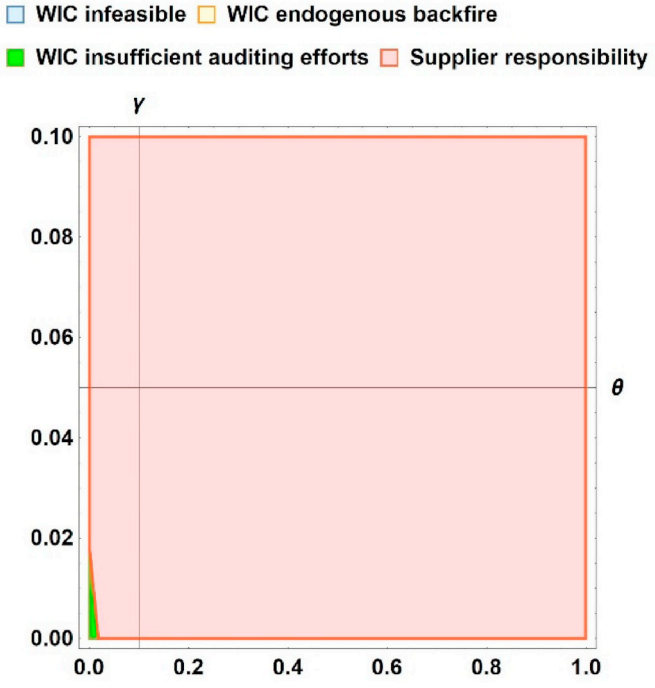

Fig. 3. Analysis of the WIC problem with respect to γ and θ

- Incentive compatibility problem with insufficient auditing efforts, in which the present auditing efforts do not lead to responsible sourcing but higher ones do
- Supplier responsibility, in which the present auditing efforts lead to responsible sourcing

The default values for the parameters are presented in Table 4. Generally, there is no clear relationship between production costs (c_E and c_U) and unit auditing costs (c_a). For example, Caro et al. (2018)

Table 4
Default values for the parameters of the SIC and WIC problems.

Parameter name	Parameter value
δ	0.9
c_a	0.8
k	0.2
θ	0.5
c_E	0.3
c_U	0.2

considered auditing costs that were higher than production costs in their investigations, while Chen and Slotnick (2015) considered c_a between c_E and c_U. The nature of auditing seems quite different from that of production. Auditing seems to have a project nature, while production has an operational nature.[7] In this case, auditing may involve different costs, risks and considerations that production never faces, such as determining auditor competence, professional judgment, verifying information, etc. (ISO, 2018). According to Propositions 7 and 8, the default value of the c_a parameter is such that there exists an endogenous backfiring condition for both problems, i.e., $c_a > 1 - c_E$ and $c_a > Min\{\widehat{c}_{a1}, Max\{\widehat{c}_{a2}, \widehat{c}_{a3}\}\}$ hold.

According to the data in Table 4, we conclude that both the SIC and WIC problems are feasible and $\gamma^S = 0.390689,\ \gamma^W = 0$ holds.

Figs. 4–9 depict the analysis of the SIC and WIC problems with respect to the buyer's auditing efforts and the other parameters. Other figures have been provided in the online appendix (Data in Brief).

5.4.3. SIC and WIC feasibility

This section investigates the feasibility regions of the SIC and WIC problems. There exist four mutually exclusive regions with respect to the values of the parameters:

- Both the SIC and WIC problems are feasible.
- Both the SIC and WIC problems are infeasible.
- Only the WIC problem is feasible.
- Only the SIC problem is feasible.

The default values for the parameters are presented Table 4. According to Proposition 9, the default values of the parameters guarantee the existence of an exogenous backfiring condition for the WIC problem, i.e., $0 < 1 - c_U - 3(c_E - c_U) < 1 - k$ holds and $\widehat{\theta}_1 = 0.625$ and $\theta = 0.5 < 0.625$ generates a feasible WIC problem.

Figs. 10–14 depict the feasibility regions with respect to different combinations of parameters. Other figures have been provided in the online appendix.

The exogenous backfiring condition for the WIC problem is observed in Figs. 10–13, where we move from the red region to the green region by increasing the value of θ. This means that lower values of external auditing efforts lead to responsible sourcing from the point of view of the WIC problem, but higher ones do not.

An important feature of an auditing mechanism can be its robustness with respect to the supplier's incentives for irresponsible production (the $c_E - c_U$ indicator). In Fig. 14, we observe that the SIC problem is more robust than the WIC problem in this parameter setting because the WIC problem becomes infeasible more quickly than the SIC problem when the $c_E - c_U$ indicator increases. This robustness is dependent on the parameter setting. In Fig. 15, we observe that the WIC problem is more robust under a different parameter setting. This robustness can also be dependent on the values of c_E and c_U. In Fig. 16, we observe that the WIC problem is more robust when the value of c_E falls into the interval of $[0, 0.2]$, while the SIC problem is more robust when it falls into the interval of $[0.3, 0.8]$.

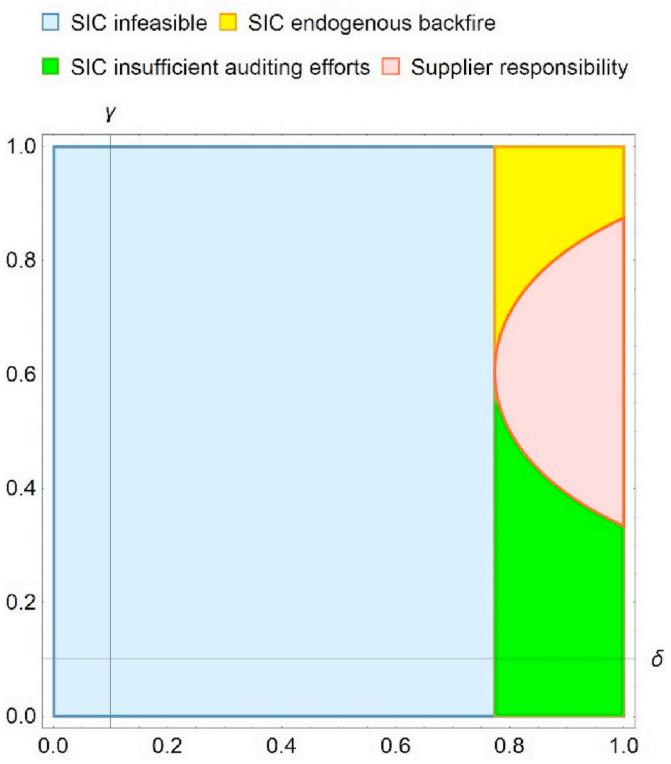

Fig. 4. Analysis of the SIC problem with respect to γ and δ

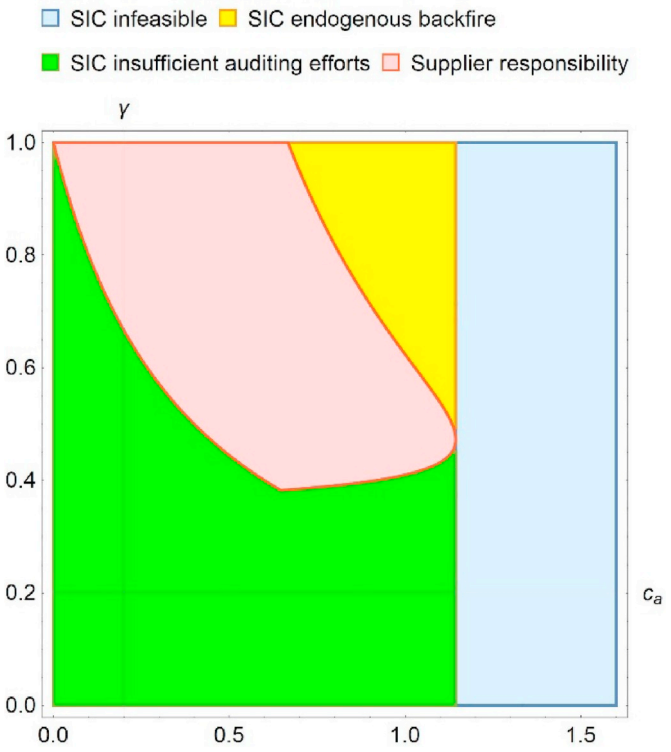

Fig. 5. Analysis of the SIC problem with respect to γ and c_a

[7] According to the PMBOK standard, a project is "a temporary endeavor undertaken to create a unique product, service, or result," while operations are "ongoing endeavors that produce repetitive outputs" (Rose, 2013).

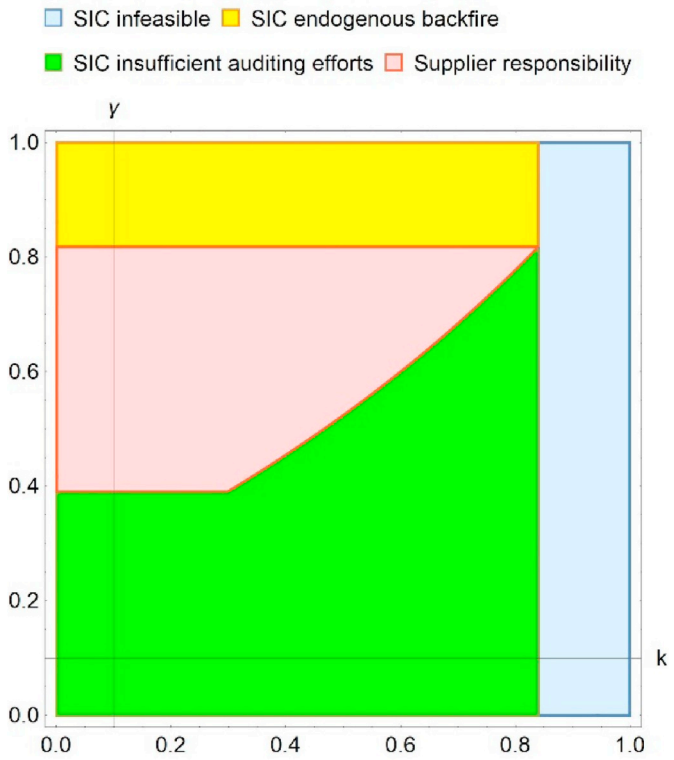

Fig. 6. Analysis of the SIC problem with respect to γ and k

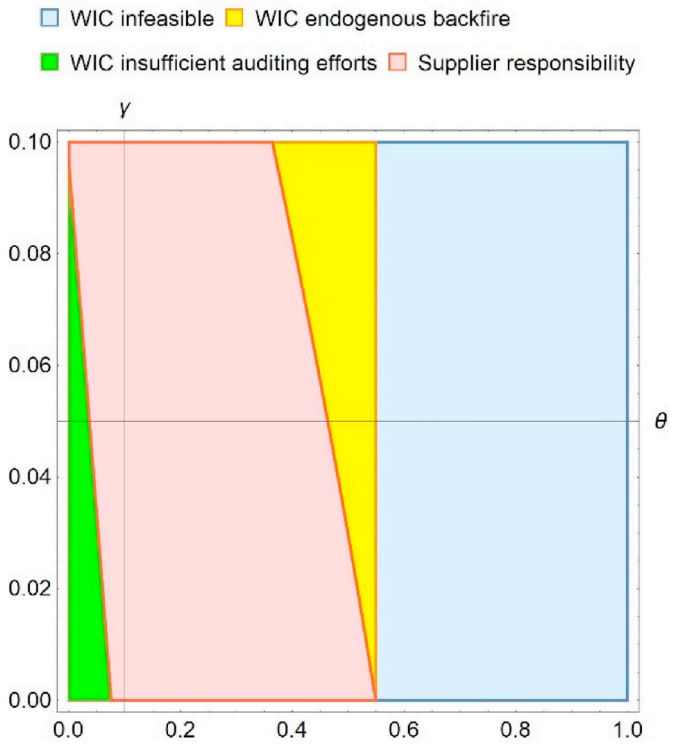

Fig. 7. Analysis of the WIC problem with respect to γ and θ

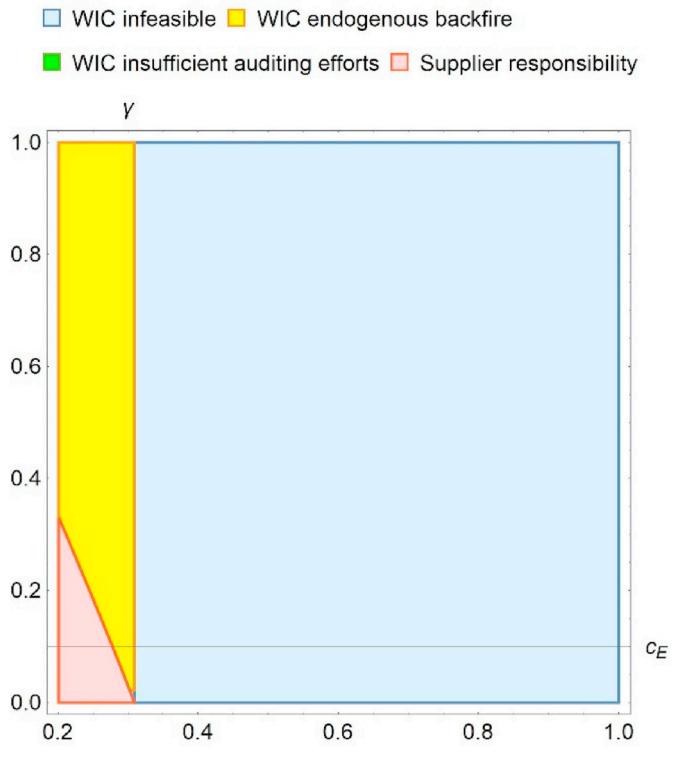

Fig. 8. Analysis of the WIC problem with respect to γ and c_E

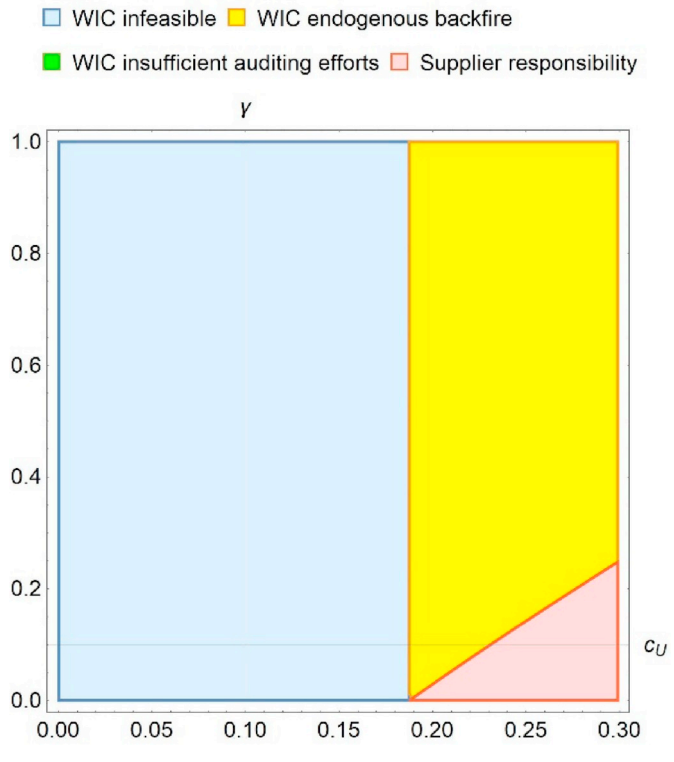

Fig. 9. Analysis of the WIC problem with respect to γ and c_U

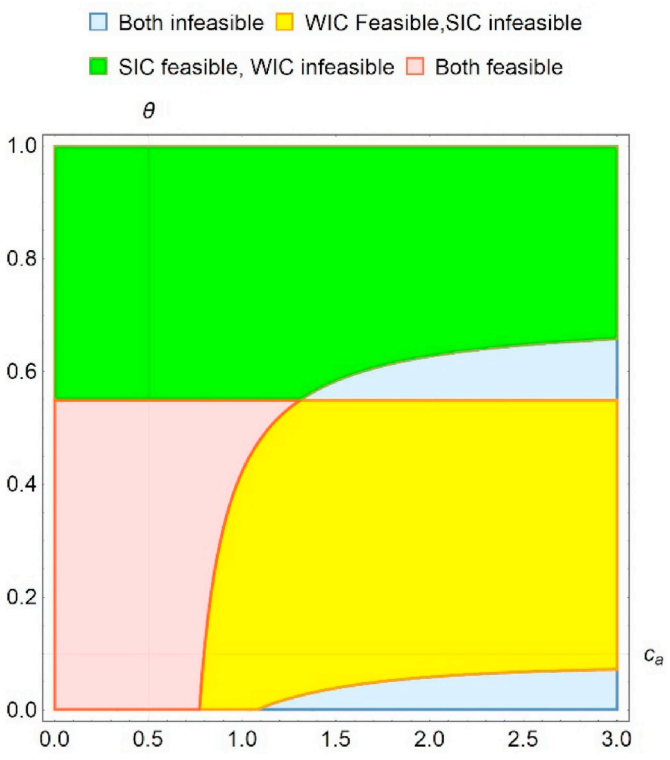

Fig. 10. Feasibility regions with respect to c_a and θ

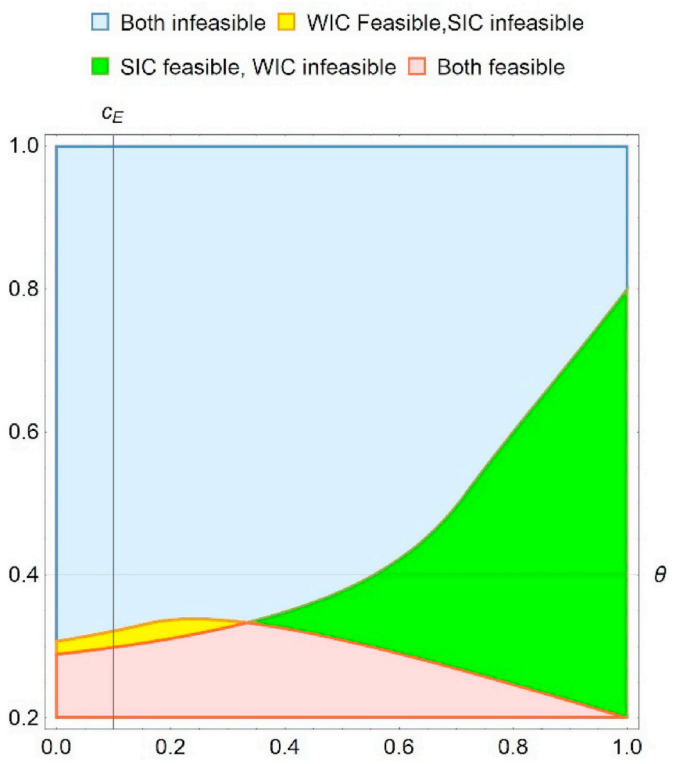

Fig. 12. Feasibility regions with respect to θ and c_E

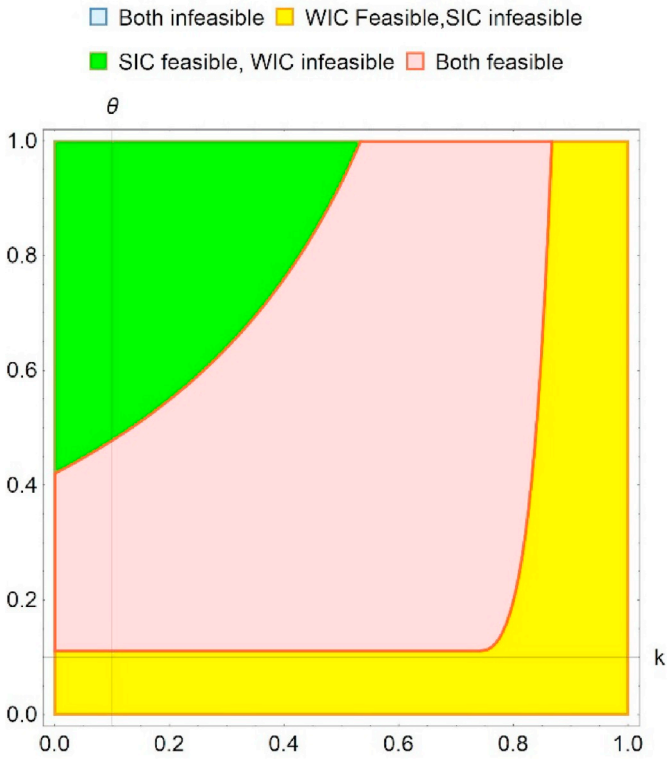

Fig. 11. Feasibility regions with respect to k and θ

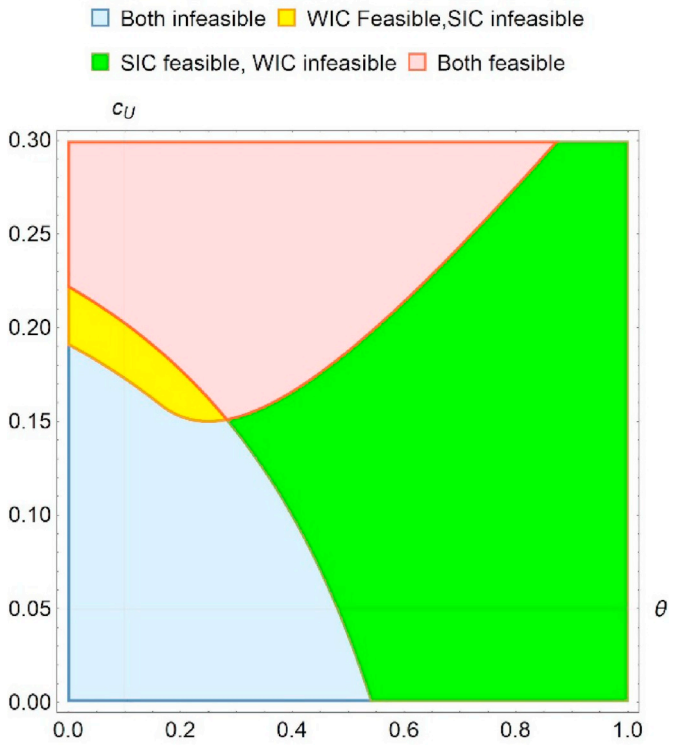

Fig. 13. Feasibility regions with respect to θ and c_U

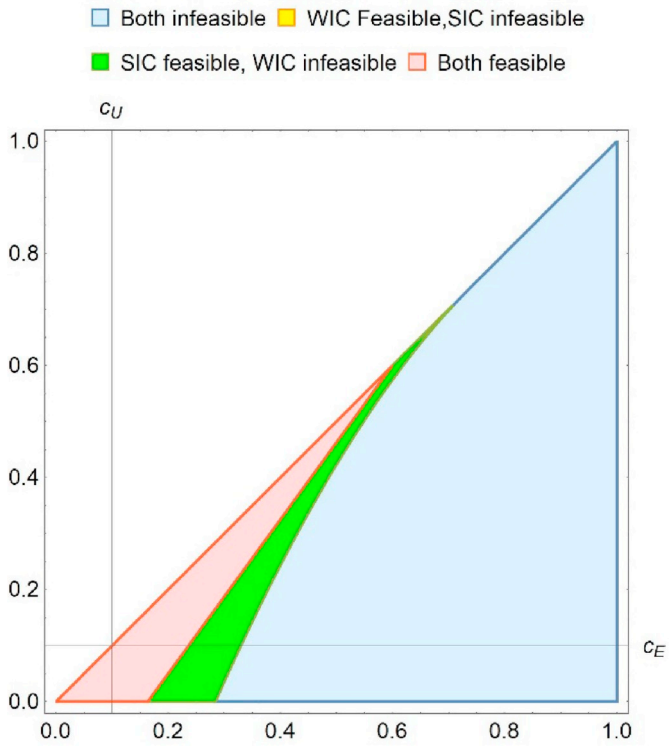

Fig. 14. Feasibility regions with respect to c_E and c_U

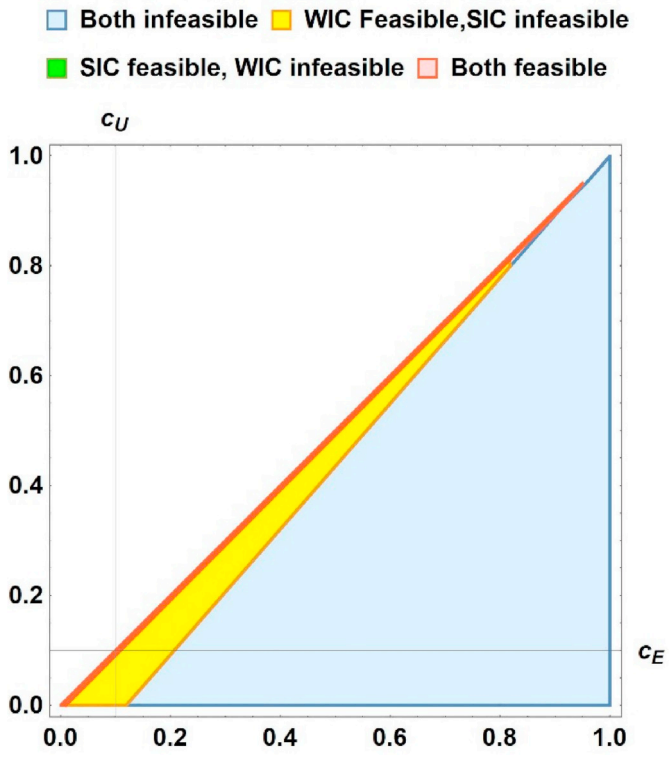

Fig. 15. Feasibility regions with respect to c_E and c_U under the parameter setting $\delta = 0.4,\ \ c_a = 1,\ \ k = 0.95,\ \ \theta = 0.9$

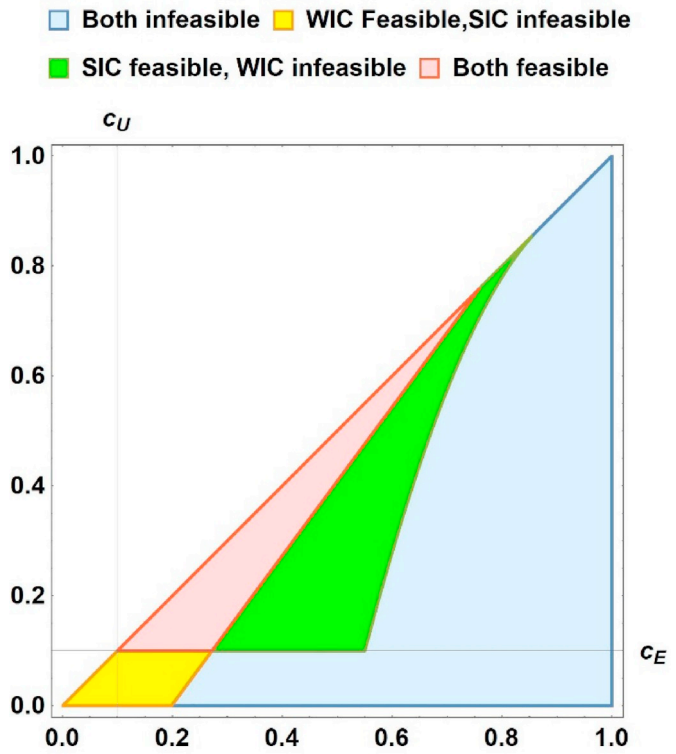

Fig. 16. Feasibility regions with respect to c_E and c_U under the parameter setting $\delta = 0.9,\ \ c_a = 0.3,\ \ k = 0.4,\ \ \theta = 0.4$

6. Discussion

In this section, we discuss the results and provide some implications for academic scholars and supply chain stakeholders.

6.1. Responses to research questions 1-4

Response to Question 1: In this paper, we proposed two auditing mechanisms to induce responsible sourcing in supply chains: the WIC and SIC problems. Our results show that each problem involves two feasibility conditions. After simplifying these conditions and using numerical analyses, we find that low values of the supplier's incentive for irresponsible production $(c_E - c_U)$ and high values of the discount rate (δ) are two necessary requirements for both problems to be feasible and for the related auditing mechanisms to be effective to induce responsible sourcing. Also, high values of external auditing efforts (θ) and consumer awareness $(1-k)$ are necessary components for SIC feasibility. Surprisingly, the behavior of the WIC problem with regard to these two parameters is quite different from that of the SIC problem. Low consumer awareness is necessary for WIC feasibility. In addition, if the WIC problem faces an exogenous backfiring condition, low external auditing efforts are necessary for its feasibility.

The above-mentioned difference between the SIC and WIC problems originates from their different behaviors toward the irresponsible sourcing equilibrium. The SIC problem holds the wholesale price of the irresponsible sourcing equilibrium lower than the irresponsible production costs, while the WIC problem tries to set it higher than the responsible production costs. In this case, the significant financial consequences of external auditing efforts and consumer awareness favor SIC feasibility, while threatening WIC feasibility.

Response to Question 2: This question is answered with the help of the concept of the *exogenous backfiring condition.* This condition arises when the buyer's auditing mechanism is effective with lower values of exogenous auditing efforts (θ), while higher values of θ make it

ineffective to induce responsible sourcing. If the exogenous backfiring condition does not exist, the increasing the total number of external auditors always results in better conditions for responsible sourcing.

We showed that the SIC problem never faces such a backfiring condition, while the WIC problem may face it. The exogenous backfiring condition for the WIC problem involves two adverse consequences for responsible sourcing. First, it may increase the buyer's auditing efforts due to the switch to the SIC problem. Consider the parameter setting $(\delta, c_a, k, c_E, c_U) = (0.9, 0.8, 0.4, 0.3, 0.2)$. In this case, the WIC problem is feasible when $\theta = 0.4$ holds and the optimal value of auditing efforts (γ^W) is equal to 0. When θ increases to the value of 0.8, the WIC problem becomes infeasible but the SIC problem is feasible. If the buyer aims to induce responsible sourcing it must increase its auditing efforts to $\gamma^S = 0.348$. Second, the exogenous backfiring condition may cause the auditing mechanism to become totally ineffective. As shown in Fig. 10, the WIC problem is feasible under the parameter setting $(\delta, c_a, k, \theta, c_E, c_U) = (0.9, 1.5, 0.4, 0.2, 0.3, 0.2)$, but both the SIC and WIC problems are infeasible when θ increases to the value of 0.55. In this case, an increase in the value of θ from 0.4 to 0.55 pushes the supply chain from responsible sourcing toward irresponsible sourcing.

Response to Question 3: As indicated in the response to Question 1, high consumer awareness will always be desirable if the buyer chooses the SIC problem for its auditing mechanism. However, high consumer awareness is not desirable if the buyer chooses the WIC problem for its auditing mechanism. The first reason is that the WIC problem may be infeasible under this situation. The second reason, according to Proposition 9, is that this situation may activate the exogenous backfiring condition.

Response to Question 4: When the *endogenous backfiring condition* does not exist, the buyer's transparency and responsible sourcing are always consistent with each other. But when there is an endogenous backfiring condition, the objectives of the buyer's transparency and the supplier's responsibility conflict with each other. The reason for this condition is that the auditing mechanism involves an unintended consequence: Although more auditing efforts by the buyer increase the potential for the discovery of irresponsible sourcing, they decrease the supplier's wholesale price. Because the supplier requires an efficiency wage for compliance with responsible sourcing standards, this unintended consequence may offset the greater potential for discovery when the buyer increases its auditing efforts. According to Propositions 7 and 8, the unit auditing cost is the key parameter for the endogenous backfiring condition. Both the SIC and WIC problems face (do not face) this condition under high (low) values of unit auditing costs (c_a). In addition, consumer awareness is irrelevant to the endogenous backfiring condition for the SIC problem, while high consumer awareness may push the WIC problem toward the endogenous backfiring condition.

6.2. Practical implications for the buyer and the response to Question 5

This section provides some guidance for the buyer in choosing a suitable mechanism between the SIC and WIC problems.

If only one of the problems is feasible, the buyer must choose the feasible problem to induce responsible sourcing. If both problems are feasible, the following criteria can help the buyer choose a suitable mechanism:

Auditing efforts: According to Corollary 4, the SIC problem incurs more auditing efforts compared to the WIC problem.

Exogenous backfiring condition: According to Proposition 9, the SIC problem does not face this condition, but the WIC problem may face it.

Endogenous backfiring condition: According to Propositions 7 and 8, consumer awareness has no effect on the endogenous backfiring condition for the SIC problem. In contrast, high consumer awareness may result in the endogenous backfiring condition for the WIC problem.

Robustness with respect to the supplier's incentive for irresponsible production: Numerical analysis (Figs. 14–16) shows no general rule for this robustness.

Table 5
Some comparisons between the SIC and WIC problems with respect to different criteria.

Criterion	The SIC problem is preferred.	The WIC problem is preferred.
The buyer's auditing efforts and profits	Never	Always
The risk of the exogenous backfiring condition	Always	Never
The risk of the endogenous backfiring condition	Conditional on the parameter setting	Conditional on the parameter setting
Robustness with respect to the supplier's incentive for irresponsible sourcing	Conditional on the parameter setting	Conditional on the parameter setting
Robustness with respect to an increase in consumer awareness	Always	Never

Robustness with respect to an increase in consumer awareness: As noted in Section 1, consumer social and environmental awareness is increasing. This phenomenon has no adverse effect on the SIC problem but threatens the WIC problem: it may make the WIC problem infeasible and result in endogenous and exogenous backfiring conditions.

Table 5 summarizes some guidance for the buyer in choosing a suitable incentive compatibility problem when both problems are feasible.

If both the SIC and WIC problems are infeasible, what should the buyer do? There are some solutions to deal with this issue. Each solution imposes some costs and barriers on the buyer. First, the buyer can abandon responsible sourcing. Although no auditing efforts are effective in this case and the buyer intends to reduce them to zero, this action cannot be taken freely. The reason, as noted in Section 1, is the existence of external forces inducing the buyer to increase or retain its transparency.

Second, the buyer can pay the high switching costs and switch to a responsible supplier. The third solution is to change the market in which the buyer sells its product. If the buyer aims to use the WIC (SIC) problem, migrating to a market with lower (higher) consumer awareness may result in the WIC (SIC) feasibility.

6.3. Practical implications for the relationship between the buyer and external stakeholders

The buyer and external stakeholders should coordinate their decisions. For example, if the SIC problem is feasible, external stakeholders should encourage the buyer to choose the SIC problem, which enables them to freely increase their auditing efforts. This is due to the fact that the SIC problem never faces an exogenous backfiring condition. In addition, if the buyer chooses the WIC problem to induce responsible sourcing, external stakeholders should carefully initiate programs that increase consumer awareness because these programs may make the WIC problem infeasible. Finally, when the buyer faces an endogenous backfiring condition, it should resist the pressure of external stakeholders to increase transparency because transparency and responsible sourcing are in conflict with each other.

6.4. The study's contributions and comparisons with other studies

Our study contributes to the literature on auditing mechanisms by investigating the effects of audits on the tactical decisions of supply chains. Our results show that the supplier requires an efficiency wage for compliance with responsible sourcing standards. In this case, auditing mechanisms in supply chains face an unintended consequence: higher auditing efforts by the buyer reduce the supplier's wholesale price, and this reduction may offset the greater potential for discovery created by higher auditing efforts. We show that both internal audits by buyers and external audits by stakeholders may involve backfiring conditions.

These backfiring conditions mean that higher auditing efforts generate adverse outcomes, i.e., lower auditing efforts induce responsible sourcing but higher ones do not.

Caro et al. (2018), Plambeck and Taylor (2016), and Chen and Lee (2017) studied the buyer's auditing mechanisms. However, they did not investigate the effect of auditing on the tactical decisions of the supply chain, and these decisions were assumed to be exogenous. In addition, these studies did not examine repeated interactions or the termination punishment of a noncompliant supplier, two aspects of real-life supply chains.

Li (2014) and Plambeck and Taylor (2016) sought strategic wholesale prices to mitigate supplier opportunism. However, critical suppliers may not consent to such pricing because they can influence the determination of the wholesale price in the procurement contract between the buyer and the supplier. Chen and Baddam (2015) and Guo et al. (2016) studied the relationship between responsible sourcing and supplier selection strategies. However, supplier switching strategies will impose high costs on the buyer if critical suppliers are involved.

Our perspective on supply chain transparency is different from that of Guo et al. (2016). According to Cramer (2008), announcing sustainability conditions at suppliers' factories is an important aspect of supply chain transparency. Supply chain audits can play this announcement role. Therefore, the total probability of supply chain audit per selling period represents our indicator for transparency. Also, Chen and Slotnick (2015) and Karaer et al. (2017) studied only a full-disclosure mechanism. Therefore, these papers neglected an optimal partial disclosure (optimal auditing mechanism) as an important transparency program. Chen et al. (2018) found that the buyer's transparency in disclosing the name of the supplier may be in conflict with responsible sourcing. Our study increases the knowledge about the relationship between supply chain transparency and responsible sourcing. We show that the buyer's transparency in disclosing sustainability conditions at the supplier's factories may be in conflict with responsible sourcing.

Plambeck and Taylor (2016) and Orsdemir et al. (2019) showed that auditing mechanisms in supply chains may face backfiring conditions because of suppliers' hiding efforts and the decision to vertically integrate the supply chain, respectively. Our study reveals other aspects of backfiring conditions for supply chain audits by showing the effects of auditing mechanisms on the tactical decisions of supply chains.

By developing the concepts of endogenous and exogenous backfiring conditions, we show that there may be a positive or negative relationship between supply chain transparency and responsible sourcing. In contrast, Porteous et al. (2015) concluded that there is no significant relationship between these two factors. Guo et al. (2016) and Chen and Baddam (2015) found that the probability of discovery of violation (transparency) and consumer punishment for irresponsible production (consumer awareness) always favor responsible sourcing. We showed that these two factors may threaten responsible sourcing if the buyer chooses the WIC problem for its auditing mechanism. In the problems studied by Guo et al. (2016) and Chen and Baddam (2015), there are two types of suppliers whose responsibility levels are determined exogenously, and the buyer freely chooses between them. Therefore, the financial consequences of these two parameters only encourage the buyer to change suppliers. However, in our problem, there is no specifically responsible supplier and the buyer tries to endogenously increase the responsibility level of a monopolist and critical supplier. In this case, we showed that the financial consequences of the two parameters may threaten the buyer's flexibility to design an auditing mechanism to induce responsible sourcing.

7. Conclusions

This paper studies a responsible sourcing problem and investigates the effect of auditing mechanisms on the tactical decisions of supply chains. We study a repeated interaction problem with one buyer and one critical supplier that has pricing power. The buyer aims to design an auditing mechanism so that sourcing from the supplier can be credibly terminated contingent on the discovery of irresponsible production. There are two equilibria in the problem that the agents can choose between: the responsible and irresponsible sourcing equilibria. The buyer can design two types of incentive compatibility mechanisms to induce responsible sourcing. In the SIC problem, the irresponsible sourcing equilibrium leads to the shutting down of production. But in the WIC problem, it leads to responsible production. In addition to the buyer, there are additional stakeholders outside the supply chain that audit the supplier.

We find that both internal and external audits within a supply chain may face backfiring conditions in which supply chain transparency conflicts with responsible sourcing. These conditions are important due to the existence of anti-sweatshop campaigns that attempt to promote responsible sourcing and increase transparency in supply chains simultaneously. When there is a backfiring condition, these campaigns can concentrate on only one of them. This research finds that the SIC problem never faces exogenous backfiring condition and may face the endogenous backfiring condition, while the WIC problem may face both. If the unit cost of auditing is high (low) enough, then the SIC and WIC problems will (will not) face endogenous backfiring conditions.

In addition, this paper investigates the conditions in which each incentive compatibility problem is feasible. These conditions are important because they determine the effectiveness of the related auditing mechanisms in inducing responsible sourcing. We find that the SIC problem is not feasible when final consumers are not socially and environmentally aware enough and respond leniently to the discovery of irresponsible sourcing. In contrast, the WIC problem is, surprisingly, not feasible when consumers are highly aware.

Our research is not without limitations, and we propose some future research directions. The investigated competition between the buyer and the supplier in negotiating the wholesale price contract involves an underlying assumption that the bargaining powers of the buyer and the supplier are equal. These equal powers lead to equal profits for them in both the responsible and irresponsible sourcing equilibria, as shown in Equations (18) and (21). Therefore, it would be helpful for future studies to relax this assumption and investigate the effect of the supplier's bargaining power on responsible sourcing. We also assumed that the degree of awareness is the same for all consumers. For future research, it would be relevant to study how heterogeneity in consumers' awareness affects the buyer's auditing mechanism, and ultimately responsible sourcing. We also assumed that there is no empathy or trust in the relationship between the buyer and the supplier. Therefore, for future research, a combination of the auditing mechanism with other mechanisms such as informal governance mechanisms could be investigated. In informal mechanisms, empathy and trust between the buyer and the supplier may create conditions that contribute to responsible sourcing. In addition, we could also consider different strategies used by external stakeholders to push the supply chain toward responsible sourcing, such as consumer awareness programs.

Acknowledgements

The authors acknowledge the editorial team, the anonymous reviewers and the editors, for their helpful comments and the processing of the manuscript. They also greatly thank Professor Charles Corbett, the faculty of operations management and sustainability at the UCLA Anderson School of Management, and his colleagues for their useful feedback and suggestions. The final version of the manuscript is the sole responsibility of the authors, and not of anyone being thanked.

Appendix

The definitions of expressions

$$A_1 \equiv (3\theta-2)c_a - 3(1-\theta)(1-c_E) \tag{A.1}$$

$$A_2 \equiv \delta(2-3\theta) + (3+\delta(3\theta-5))c_E - 3(1-\delta)c_U \tag{A.2}$$

$$A_3 \equiv \theta c_a - (1-\theta)(1+2c_U - 2(1-k)\theta - 3c_E) \tag{A.3}$$

$$A_4 \equiv \delta\theta(1-(1-k)\theta) - 3(1-(1-\theta)\delta)c_E + (3(1-\delta)+2\delta\theta)c_U \tag{A.4}$$

$$A_5 \equiv 2(1-\theta)((1-k)(1-\theta)+c_a) > 0 \tag{A.5}$$

$$A_6 \equiv Min\left\{\frac{1-c_E}{c_a}, \frac{-\delta A_1 + \sqrt{\delta^2 {A_1}^2 - 12\delta c_a(1-\theta)A_2}}{6\delta(1-\theta)c_a}\right\} \tag{A.6}$$

$$A_7 \equiv Min\left\{\frac{1+2c_U-\theta(1-k)-3c_E}{c_a+(1-\theta)(1-k)}, \frac{-\delta A_3 + \sqrt{\delta^2 {A_3}^2 + 2\delta A_4 A_5}}{\delta A_5}\right\} \tag{A.7}$$

$$\widehat{c}_1 \equiv \frac{\delta {c_a}^2(2-3\theta)^2 + 9\delta(1-c_E)^2(1-\theta)^2 - 6\delta c_a(1-\theta)(1-c_E)(2-3\theta)}{36c_a(1-\delta)(1-\theta)} \tag{A.8}$$

$$\widehat{k}_1 \equiv Min\left\{1 - \frac{c_a(c_E-c_U)}{(1-c_E)(1-\theta)+c_a\theta}, c_a + c_U\right\} \tag{A.9}$$

$$\widehat{c}_2 \equiv \theta + \frac{(1-c_E)(1-\theta)}{c_a} \tag{A.10}$$

$$S_1 \equiv 3(2+\delta(\theta-2))c_E - 2(3+\delta(\theta-3))c_U - \delta\theta \tag{A.11}$$

$$S_2 \equiv \delta + 9\delta c_E^2 + 6c_E(\delta - 2\delta c_U - 2) + 4c_U(3-2\delta+\delta c_U) \tag{A.12}$$

$$S_3 \equiv 12(1-\delta)(1-\theta)^2(c_E-c_U) > 0 \tag{A.13}$$

$$\widehat{k}_2 \equiv \frac{2c_a(1-\theta)S_1 - (1-\theta)^2 S_2 - \delta\theta^2 c_a^2}{S_3} \tag{A.14}$$

$$\widehat{k}_3 \equiv \frac{2-\theta}{2(1-\theta)}c_a + \frac{1+3c_E-2c_U}{2} \tag{A.15}$$

$$\widehat{\theta}_1 \equiv \frac{1-c_U-3(c_E-c_U)}{1-k} \tag{A.16}$$

$$\widehat{c}_3 \equiv \frac{\delta(k-c_a-c_U)}{3} \tag{A.17}$$

$$\widehat{c}_4 \equiv \frac{(1-\theta)(1-c_U-2(1-k)\theta) - \theta c_a}{3(1-\theta)} \tag{A.18}$$

$$\widehat{c}_5 \equiv \frac{\delta\theta(1-c_U-(1-k)\theta)}{3(1-\delta(1-\theta))} \tag{A.19}$$

$$\widehat{c}_6 \equiv \frac{\theta c_a}{3(1-\theta)} + \frac{1-c_U}{3} \tag{A.20}$$

$$\widehat{\delta}_1 \equiv \frac{3(c_E-c_U)}{1+2c_E-c_a-3c_U} \tag{A.21}$$

$$\widehat{c}_{a1} \equiv k + 2c_U - 3c_E \tag{A.22}$$

$$\widehat{c}_{a2} \equiv \frac{3(c_E-c_U) - (1-k)(1-\theta)^2 - \delta(3c_E(1-\theta)+\theta-(1-k)\theta^2 + c_U(2\theta-3))}{2(1-\theta)} \tag{A.23}$$

$$\widehat{c}_{a3} \equiv k - c_U - \frac{3(c_E-c_U)}{\delta} \tag{A.24}$$

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.109721.

References

Heese, H.S., Kemahlioglu-Ziya, E., 2014. Enabling opportunism: revenue sharing when sales revenues are unobservable. Prod. Oper. Manag. 23, 1634–1645.

Agrawal, V.V., Lee, D., 2016. Responsible Sourcing, Environmentally Responsible Supply Chains. Springer, pp. 71–86.

Apple, 2013. Apple Supplier Responsibility 2013 Progress Report. https://www.apple.com/supplier-responsibility/pdf/Apple_SR_2013_Progress_Report.pdf.

Apple, 2018. Apple Supplier Responsibility 2018 Progress Report. https://www.apple.com/supplier-responsibility/pdf/Apple_SR_2018_Progress_Report.pdf.

Apple, 2019. Apple Supplier Code of Conduct. https://www.apple.com/supplier-responsibility/pdf/Apple-Supplier-Code-of-Conduct-January.pdf.

Arya, A., Mittendorf, B., Sudbury, A., 2015. Forward contracting and incentives for disclosure. Rev. Account. Stud. 20, 1093–1121.

Awasthy, P., Hazra, J., 2019. Responsible sourcing by improving workplace safety through buyer–supplier collaboration. Eur. J. Oper. Res. 274, 155–164.

Balachandran, K.R., Wang, H.-W., Li, S.-H., Wang, T., 2013. In-house capability and supply chain decisions. Omega 41, 473–484.

Bartley, T., 2007. Institutional emergence in an era of globalization: the rise of transnational private regulation of labor and environmental conditions. Am. J. Sociol. 113, 297–351.

Bolt, W., Houba, H., 2006. Credible Threats in Negotiations: A Game-Theoretic Approach. Springer Science & Business Media.

Brownlee, J., 2011. Foxconn Employee Commits Suicide after iPad 2 Factory Explosion. https://www.cultofmac.com/97250/foxconn-employee-commits-suicide-after-ipad-2-factory-explosion-breaking/.

Brusset, X., Agrell, P.J., 2017. Intrinsic impediments to category captainship collaboration. J. Ind. Manag. Optim. 13, 113–133.

Bulletin, C.L., 2018. Reform of Labour Contract Law Unlikely at This Year's National People's Congress. http://www.clb.org.hk/content/reform-labour-contract-law-unlikely-year%E2%80%99s-national-people%E2%80%99s-congress.

Caro, F., Chintapalli, P., Rajaram, K., Tang, C.S., 2018. Improving supplier compliance through joint and shared audits with collective penalty. Manuf. Serv. Oper. Manag. 20, 363–380.

Castka, P., Corbett, C.J., 2016. Governance of eco-labels: expert opinion and media coverage. J. Bus. Ethics 135, 309–326.

Chen, J.-Y., Baddam, S.R., 2015. The effect of unethical behavior and learning on strategic supplier selection. Int. J. Prod. Econ. 167, 74–87.

Chen, J.-X., Chen, J., 2017. Supply chain carbon footprinting and responsibility allocation under emission regulations. J. Environ. Manag. 188, 255–267.

Chen, L., Lee, H.L., 2017. Sourcing under supplier responsibility risk: the effects of certification, audit, and contingency payment. Manag. Sci. 63, 2795–2812.

Chen, J.-Y., Slotnick, S.A., 2015. Supply chain disclosure and ethical sourcing. Int. J. Prod. Econ. 161, 17–30.

Chen, S., Zhang, Q., Zhou, Y.P., 2018. Impact of supply chain transparency on sustainability under NGO scrutiny. Prod. Oper. Manag. https://doi.org/10.1111/poms.12973.

Choi, S.C., 1991. Price competition in a channel structure with a common retailer. Mark. Sci. 10, 271–296.

Christopher, M., 2016. Logistics & Supply Chain Management. Pearson UK.

Cramer, J., 2008. Organising corporate social responsibility in international product chains. J. Clean. Prod. 16, 395–400.

Daddi, T., Testa, F., Frey, M., Iraldo, F., 2016. Exploring the link between institutional pressures and environmental management systems effectiveness: an empirical study. J. Environ. Manag. 183, 647–656.

Dai, X., Lin, Y.-T., Shi, R., Xu, D., 2018. A manufacturer's responsible sourcing strategy: going organic or participating in fair trade? Ann. Oper. Res. https://doi.org/10.1007/s10479-018-3090-x.

Doorey, D.J., 2011. The transparent supply chain: from resistance to implementation at Nike and Levi-Strauss. J. Bus. Ethics 103, 587–603.

Earnhart, D., Leonard, J.M., 2013. Determinants of environmental audit frequency: the role of firm organizational structure. J. Environ. Manag. 128, 497–513.

Economics, T., 2019. China interest rate 2019. https://tradingeconomics.com/china/interest-rate.

Economist, T., 2017. China's Labour Law Is No Use to Those Who Need it Most. https://www.economist.com/china/2017/08/17/chinas-labour-law-is-no-use-to-those-who-need-it-most.

Egels-Zandén, N., 2007. Suppliers' compliance with MNCs' codes of conduct: behind the scenes at Chinese toy suppliers. J. Bus. Ethics 75, 45–62.

Egels-Zandén, N., Hansson, N., 2016. Supply chain transparency as a consumer or corporate tool: the case of Nudie Jeans Co. J. Consum. Policy 39, 377–395.

Elkington, J., 1998. Cannibals with Forks: the Triple Bottom Line of 21st Century Business. New Society Publishers.

Fu, X., Dong, M., Liu, S., Han, G., 2016. Trust based decisions in supply chains with an agent. Decis. Support Syst. 82, 35–46.

Guo, R., Lee, H.L., Swinney, R., 2016. Responsible sourcing in supply chains. Manag. Sci. 62, 2722–2744.

Gürtürk, A., Hahn, R., 2016. An empirical assessment of assurance statements in sustainability reports: smoke screens or enlightening information? J. Clean. Prod. 136, 30–41.

Harbaugh, R., Maxwell, J.W., Roussillon, B., 2011. Label confusion: the Groucho effect of uncertain standards. Manag. Sci. 57, 1512–1527.

Heese, H.S., Kemahlıoğlu-Ziya, E., 2016. Don't ask, don't tell: sharing revenues with a dishonest retailer. Eur. J. Oper. Res. 248, 580–592.

Huang, J., Leng, M., Parlar, M., 2013. Demand functions in decision modeling: a comprehensive survey and research directions. Decis. Sci. J. 44, 557–609.

Huo, B., Wang, Z., Tian, Y., 2016. The impact of justice on collaborative and opportunistic behaviors in supply chain relationships. Int. J. Prod. Econ. 177, 12–23.

Hwang, W., Bakshi, N., DeMiguel, V., 2018. Wholesale price contracts for reliable supply. Prod. Oper. Manag. 27, 1021–1037.

ISO, 2018. ISO 19011:2018(en) Guidelines for auditing management systems. https://www.iso.org/obp/ui/#iso:std:iso:19011:ed-3:v1:en.

Karaer, Ö., Kraft, T., Khawam, J., 2017. Buyer and nonprofit levers to improve supplier environmental performance. Prod. Oper. Manag. 26, 1163–1190.

Karlsson, C., 2016. Research Methods for Operations Management. Routledge.

Khosroshahi, H., Rasti-Barzoki, M., Hejazi, S.R., 2019. A game theoretic approach for pricing decisions considering CSR and a new consumer satisfaction index using transparency-dependent demand in sustainable supply chains. J. Clean. Prod. 208, 1065–1080.

Klein, B., Leffler, K.B., 1981. The role of market forces in assuring contractual performance. J. Political Econ. 89, 615–641.

Laudal, T., 2010. An attempt to determine the CSR potential of the international clothing business. J. Bus. Ethics 96, 63–77.

Li, X., 2014. Relational contracts, growth options, and heterogeneous beliefs: a game-theoretic perspective on information technology outsourcing. J. Manag. Inf. Syst. 31, 319–350.

Lin, B.-W., 2004. Original equipment manufacturers (OEM) manufacturing strategy for network innovation agility: the case of Taiwanese manufacturing networks. Int. J. Prod. Res. 42, 943–957.

Ma, P., Shang, J., Wang, H., 2017. Enhancing corporate social responsibility: contract design under information asymmetry. Omega 67, 19–30.

Macfadyen, S., Tylianakis, J.M., Letourneau, D.K., Benton, T.G., Tittonell, P., Perring, M. P., Gómez-Creutzberg, C., Báldi, A., Holland, J.M., Broadhurst, L., Okabe, K., Renwick, A.R., Gemmill-Herren, B., Smith, H.G., 2015. The role of food retailers in improving resilience in global food supply. Global Food Secur. 7, 1–8.

MacLeod, W.B., Malcomson, J.M., 1998. Motivation and markets. Am. Econ. Rev. 388–411.

Michelsen, O., de Boer, L., 2009. Green procurement in Norway; a survey of practices at the municipal and county level. J. Environ. Manag. 91, 160–167.

Miranda-Ackerman, M.A., Azzaro-Pantel, C., 2017. Extending the scope of eco-labelling in the food industry to drive change beyond sustainable agriculture practices. J. Environ. Manag. 204, 814–824.

Myerson, R.B., 2013. Game Theory. Harvard university press.

Narahari, Y., 2014. Game Theory and Mechanism Design. World Scientific.

New, S.J., 2015. Modern slavery and the supply chain: the limits of corporate social responsibility? Supply Chain Manag.: Int. J. 20, 697–707.

Orsdemir, A., Hu, B., Deshpande, V., 2019. Ensuring corporate social and environmental responsibility through vertical integration and horizontal sourcing. Manuf. Serv. Oper. Manag. 21, 417–434.

Osborne, M.J., 2004. An Introduction to Game Theory. Oxford university press, New York.

Park, J., Brorson, T., 2005. Experiences of and views on third-party assurance of corporate environmental and sustainability reports. J. Clean. Prod. 13, 1095–1106.

Pei-Ju, T., 2017. Protesters against Revisions to Taiwan Labor Law Cleared by Police. https://www.taiwannews.com.tw/en/news/3313139.

Phan, T.N., Baird, K., 2015. The comprehensiveness of environmental management systems: the influence of institutional pressures and the impact on environmental performance. J. Environ. Manag. 160, 45–56.

Plambeck, E., Denend, L., 2010. Walmart's Sustainability Strategy. OIT-71A and B. Stanford Graduate School of Business Case Study, Updated.

Plambeck, E.L., Taylor, T.A., 2016. Supplier evasion of a buyer's audit: implications for motivating supplier social and environmental responsibility. Manuf. Serv. Oper. Manag. 18, 184–197.

Porteous, A.H., Rammohan, S.V., Lee, H.L., 2015. Carrots or sticks? Improving social and environmental compliance at suppliers through incentives and penalties. Prod. Oper. Manag. 24, 1402–1413.

Porter, M.E., 2008. The five competitive forces that shape strategy. Harv. Bus. Rev. 86, 25–40.

Reefke, H., Sundaram, D., 2017. Key themes and research opportunities in sustainable supply chain management – identification and evaluation. Omega 66, 195–211.

Rose, K.H., 2013. A guide to the project management body of knowledge (PMBOK® guide)—fifth edition. Proj. Manag. J. 44 e1-e1.

Shapiro, C., Stiglitz, J.E., 1984. Equilibrium unemployment as a worker discipline device. Am. Econ. Rev. 74, 433–444.

Sheth, J.N., Parvatiyar, A., 1995. The evolution of relationship marketing. Int. Bus. Rev. 4, 397–418.

Shi, C., Chen, Y., You, J., Yao, H., 2018. Asset specificity and contractors' opportunistic behavior: moderating roles of contract and trust. J. Manag. Eng. 34, 04018026.
Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., Shankar, R., 2008. Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies. Tata McGraw-Hill Education.
Sinayi, M., Rasti-Barzoki, M., 2018. A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention. J. Clean. Prod. 196, 1443–1458.
Sinnandavar, C.M., Wong, W.-P., Soh, K.-L., 2018. Dynamics of supply environment and information system: integration, green economy and performance. Transp. Res. D Transp. Environ. 62, 536–550.
Tai, A., 2015. How to Classify Suppliers. https://alvintai.com/how-to-classify-suppliers/.
Taylor, T.A., Plambeck, E.L., 2007. Supply chain relationships and contracts: the impact of repeated interaction on capacity investment and procurement. Manag. Sci. 53, 1577–1593.
Trudel, R., Cotte, J., 2009. Does it pay to be good? MIT Sloan Manag. Rev. 50, 61–68.
Tseng, S.-C., Hung, S.-W., 2014. A strategic decision-making model considering the social costs of carbon dioxide emissions for sustainable supply chain management. J. Environ. Manag. 133, 315–322.
van den Brink, S., Kleijn, R., Tukker, A., Huisman, J., 2019. Approaches to responsible sourcing in mineral supply chains. Resour. Conserv. Recycl. 145, 389–398.
Williamson, O.E., 1975. Markets and Hierarchies. New York 2630.
Won, Y., 2017. How can a retailer identify the dominant strategy in a newsvendor situation with a supplier take-it-or-leave-it offer? Int. Trans. Oper. Res. 24, 1435–1462.
Yan, T., Kull, T.J., 2015. Supplier opportunism in buyer–supplier new product development: a China-US study of antecedents, consequences, and cultural/institutional contexts. Decis. Sci. J. 46, 403–445.
Zhu, S., Song, J., Hazen, B.T., Lee, K., Cegielski, C., 2018. How supply chain analytics enables operational supply chain transparency: an organizational information processing theory perspective. Int. J. Phys. Distrib. Logist. Manag. 48, 47–68.