SOCIALLY RESPONSIBLE OPERATIONS IN PROCUREMENT

by

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*Dedicated to my grandmother.*

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SOCIALLY RESPONSIBLE OPERATIONS IN PROCUREMENT

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This dissertation explores issues regarding socially responsible operations in procurement. When buying firms outsource to upstream suppliers, the potential of socially irresponsible actions from suppliers is an important concern. To prevent or mitigate such behavior, buyers often use informational tools such as *audits* and/or monetary actions such as *paying higher wholesale prices*. This dissertation consists of three main chapters. The first two main chapters highlight the importance of prioritizing the auditing of structurally-important suppliers in the supply network by considering exogenous responsibility efforts of the suppliers in Chapter 2 and endogenous responsibility efforts of the suppliers in Chapter 3, respectively. In Chapter 4, we examine the behavioral impact of a buyer's wholesale price on a supplier's responsibility effort.

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# CHAPTER 1

# INTRODUCTION

The noncompliance of social responsibility by suppliers, such as deployment of child labor or environmental pollution, is detrimental to society and can lead to severe consequences for the buying firms who procure from the noncompliant suppliers. This dissertation considers two tools for buying firms – *audits* and *paying higher wholesale prices* – to mitigate the risk of social irresponsibility stemming from suppliers.

In the first two chapters, we highlight the importance of prioritizing the auditing of structurally-important suppliers in the supply network. Most supply networks are characterized by firms that source from multiple suppliers and suppliers that serve multiple firms, thus resulting in suppliers who differ in their *degree centrality*, i.e., the number of firms they supply to. In such networks, any negative publicity from suppliers' noncompliance of socially-responsible practices – e.g., employment of child labor, unsafe working conditions, and excessive pollution – can significantly damage the reputation of the buying firms. To mitigate this impact, firms preemptively audit suppliers (e.g. an in-depth review of the supplier's infrastructure, operating practices and workforce, facility visits and on-site guidance, preparation of a corrective action plan, etc.), although resource and time considerations typically restrict the number of suppliers a firm can audit. Therefore, a key question is whether firms should prioritize the auditing of suppliers with low or high centrality, *ceteris paribus*. To investigate, we consider an assembly network consisting of two firms (buyers) and three suppliers – each firm has one *independent supplier* who uniquely supplies to that firm and one *common supplier* who supplies to both. We find that downstream competition between the firms drives them away from auditing the supplier with higher centrality; i.e., the common supplier, in equilibrium, despite the fact that auditing this supplier is better for the aggregate profit of the firms. We show that this inefficiency is corrected when the firms cooperate (via a stable coalition) to *jointly audit* the suppliers and share the auditing cost in a fair manner. We also identify conditions under which joint auditing improves social welfare. In particular, we consider the scenario where the suppliers' responsibility efforts are exogenous in Chapter 2 and the scenario where the suppliers endogenously decide their responsibility efforts in Chapter 3.

In Chapter 4, we examine the behavioral impact of a buyer's wholesale price on a supplier's responsibility effort. To mitigate the noncompliance of social responsibility by suppliers, a commonly held view is that buyers should pay high wholesale prices to suppliers because the socially responsible practices are costly. However, Plambeck and Taylor (2016) show that offering a higher wholesale price may backfire with the supplier behaving less responsibly. We test the theory in a controlled human-subject experiment and find that while the theory is qualitatively supported when the buyer either does not make active wholesale price decisions or constantly offers the low wholesale price, significant deviations are identified otherwise, resulting in a lower responsibility effort of the supplier and a lower supply chain surplus. We find that trust of the subjects is a significant factor in predicting such deviations. A more trusting buyer is more likely to pay high wholesale price. A more trusting supplier is more likely to choose the more responsible action when offered high price and less likely to do so when offered low price.

# CHAPTER 2

# SUPPLIER CENTRALITY AND AUDITING PRIORITY IN SOCIALLY RESPONSIBLE SUPPLY CHAINS: EXOGENOUS RESPONSIBILITY EFFORTS OF THE SUPPLIERS[1]

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## 2.1 Introduction

Supply networks are ubiquitous across industries. Some characteristics of typical supply networks include firms that procure from multiple suppliers, suppliers that serve multiple firms who may compete in a downstream market, and suppliers that differ in their *degree centrality* – defined as the number of firms they supply to (Wang et al., 2020; Liu et al., 2019). For example, Ionis Pharmaceuticals supplies to GlaxoSmithKline (GSK) and twelve other pharmaceutical companies in the U.S., Halozyme Therapeutics supplies to Pfizer and ten other pharmaceutical companies in the U.S., while NCPC International supplies to both GSK and Pfizer, among others (Compustat 2016, SumOfUs 2015). The electronics manufacturer Pegatron serves both Apple's iPad Pro and Microsoft's Surface Pro, while TSMC (resp., Intel) supplies CPUs exclusively for the iPad Pro (resp., Surface Pro) (Bhattacharya, 2016; Crothers, 2014; Clark, 2013). As another example, the ready-made garment manufacturer Chorka Textile supplies to twenty-three different apparel brands worldwide while some others, such as Alamode Apparels, supply to only one brand (Bangladesh Accord Foundation, 2016).

In such supply networks, any negative publicity resulting from suppliers' noncompliance of social responsibility can significantly damage the brand and reputation of the buyers they supply to (Guo et al., 2016; Plambeck and Taylor, 2016; Fang and Cho, 2020). There have been several such instances in recent years: NCPC International was accused of discharging pharmaceutical effluents into the environment, and Pfizer and GSK were revealed to be among the well-known brands sourcing from this supplier (SumOfUs, 2015). Pegatron was accused for unethical labor practices and companies that sourced from this manufacturer took a reputational hit (Bhattacharya, 2016). In the industrial accident, caused by unsafe working conditions, at Rana Plaza in Bangladesh, 1,138 workers were killed and well-known apparel brands that sourced from the factories at this location, including Benetton, H&M and Walmart, were linked to the scandal (Al-Mahmood et al., 2013).

From the perspective of a buying firm, a common approach to avoid such damages resulting from suppliers' social-responsibility violations is to *audit* them. A typical audit of a supplier is both resource-intensive and time-consuming – activities include (a) an in-depth review of the supplier's infrastructure, operating practices, and workforce, (b) visits to the supplier's facilities and on-site guidance to managers, and (c) preparation of a corrective action plan, if any, and provision of training and educational programs to empower workers. Collecting the huge amount of data needed for this exercise, building systems to analyze it, and employing precious manpower, all require a significant amount of resources and time (McBeath, 2012; McCann, 2015). Consequently, buyers often choose only a subset of their suppliers to audit. For example, even a cash-rich company like Apple audited only about 50% of its suppliers in 2013 (Apple, 2015).

From a supplier's perspective, the risk of causing social harm depends on the extent of her responsibility effort: the higher this effort, the less likely it is that her actions will be harmful. It may, however, not always be possible for the supplier to adjust this effort in anticipation of an audit. For instance, the supplier may be unaware of social-responsibility standards due to, say, lack of education and/or communication, or ethical perception. This is often the case in developing economies. In his widely-cited paper, Carroll (1991) defines this type of management ethics as "amoral management" – amoral suppliers are not sensitive enough to realize that their business practices may have a harmful impact on others or on the environment; see also Carroll (2000); Cai et al. (2012), and Norberg (2018).

For a given decentralized, socially responsible network consisting of multiple buyers and multiple suppliers, the suppliers with higher (degree) centrality are especially significant for the simple reason that their social-responsibility decisions affect more buyers. This – together with our earlier observation that buyers typically audit only a subset of their suppliers – raises important questions: *(1) When buyers audit some, but not all, of their respective suppliers, how do the centralities of the suppliers affect the auditing priority of the buyers? (2) How can* *the buyers cooperate in making auditing decisions to improve their profits? (3) Are buyers' auditing decisions always in sync with a social-planner's objective of minimizing harm to society via the identification of socially irresponsible practices?*

To investigate the questions above, we develop a stylized, game-theoretic model of an assembly supply network consisting of two buyers; each buyer sources two inputs – one each from two distinct suppliers – to assemble his final product. To focus on the role of supplier centrality in the network, the two suppliers of a buyer are symmetric from the buyer's perspective except that one of the two suppliers is common to both the buyers (Figure 2.1). Thus, each buyer has one *independent supplier* who uniquely supplies to that buyer, and one *common supplier* who supplies to both the buyers. To incorporate the practice of buyers auditing only a subset of their suppliers due to resource constraints, we assume that each buyer chooses to audit at most one supplier. The buyers unilaterally and simultaneously decide which suppliers to audit as well as the extent of their respective auditing efforts. Then, the uncertainty pertaining to potential social harm from the suppliers' actions is resolved – this may be detected either by a buyer's audit or by public scrutiny (e.g., media or NGOs). If a supplier's harmful practices are discovered through a buyer's audit, then the supplier incurs additional cost to implement corrective actions and the buyer completes his procurement from the supplier. Otherwise, if they are discovered in public, then the buyer suffers a damage to the maximum willingness-to-pay (MWTP) of his customers and has to source the corresponding input at a higher wholesale price. We consider two settings – a benchmark case in which the two buyers do not engage in quantity competition in the downstream market and another in which they do.

In the benchmark case where the buyers do not compete, we find that, among the equilibria in which at least one supplier is audited, there are two types: (i) Each buyer audits his independent supplier. (ii) One buyer audits his independent supplier and the other buyer audits the common supplier. We show that the latter equilibrium is Pareto-dominant: When

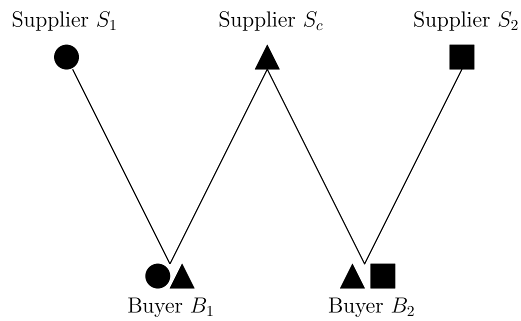


Figure 2.1. Assembly Network: Buyer $B_1$ (resp., $B_2$) Sources from Suppliers $S_1$ and $S_c$ (resp., $S_2$ and $S_c$).

the buyers do not compete (and therefore one buyer's market-clearing price is not affected by the sourcing quantity of the other buyer), a buyer is indifferent between auditing his independent supplier and the common supplier (with the same auditing effort), given that the other buyer audits his own independent supplier. However, auditing the common supplier exerts a positive externality on the other buyer, and therefore yields a Pareto-dominant outcome.

When the two buyers compete, however, we find that the buyers never audit the common supplier in equilibrium. Regardless of the other buyer's auditing decision, a buyer's audit of the common supplier intensifies downstream competition and negatively impacts his profit. Thus, while auditing the common supplier is better for the aggregate profit of the buyers, competition drives them away from auditing the common supplier.

To mitigate this inefficiency, we investigate the possibility of the buyers *jointly auditing* the suppliers – this has been implemented in practice; e.g., prominent pharmaceutical companies such as Pfizer and GSK have formed the Pharmaceutical Supply Chain Initiative (PSCI) to jointly audit their suppliers (PSCI, 2018); about 200 clothing brands and retailers jointly inspect garment factories in Bangladesh (Thomasson, 2014; Bangladesh Accord Foundation, 2018; Smith, 2016). We show that the buyers can form a *stable coalition* to jointly audit the suppliers and share the auditing cost in a fair manner based on the notion of Shapley value. Indeed, by pooling their auditing resources together and taking decisions as a combined entity, the buyers can make better decisions regarding which supplier(s) to audit and how much auditing effort to invest. We show that in any equilibrium where at least one supplier is audited, the common supplier is *always* audited. Thus, the stable joint-auditing coalition corrects the inefficiency resulting from competition (namely, the common supplier is not audited) and enables the buyers to earn higher profits relative to when they act unilaterally. We identify conditions under which the social welfare under joint auditing is higher than that under unilateral auditing.

We also analyze an alternate setting in which each buyer, when auditing unilaterally, divides his limited auditing resource among his two suppliers. When auditing jointly, the buyers pool their auditing resources and divide them among their three suppliers. For this setting too, our main managerial insight remains intact: While competition drives the buyers away from the mutually-beneficial practice of auditing their common supplier, i.e., the one with higher degree-centrality, joint-auditing helps them correct this inefficiency. The robustness of our results for the setting where the suppliers endogenously decide their responsibility efforts is discussed in Chapter 3.

## 2.2 Literature Review

Our work contributes to the growing literature on socially responsible supply chain management by examining a supply network with *multiple buyers* and *multiple suppliers*, and highlighting the role of supplier centrality in the network vis-à-vis the auditing decisions of the buyers.

Within the literature on socially responsible operations, the setting of our analysis is perhaps closest to the framework of Plambeck and Taylor (2016), who study the effectiveness of audits in a supply chain with *one buyer* and *one supplier*, under the possibility that the supplier can hide her unsafe practices from the buyer's audit. There are several contexts in which the use of audits/inspections has been explored for improving a supplier's socially responsible actions in a *one-buyer-one-supplier* framework; e.g., managing product adulteration (Babich and Tang, 2012), combating child labor (Cho et al., 2019), managing a supplier's social-responsibility risk (Chen and Lee, 2017), and preventing supplier-auditor collusion (Chen et al., 2020).

Our work is also related to studies that examine the practice of joint-auditing in socially responsible supply chains where *multiple buyers share one supplier*: Fang and Cho (2020) address cooperation among multiple manufacturers in jointly auditing a common supplier. Caro et al. (2018) study cooperation between two buyers in auditing one supplier. In contrast, we consider a supply network with multiple buyers and multiple suppliers, and explore how joint-auditing can correct the inefficiencies that result from actions driven by selfish incentives of the buyers.

The auditing of suppliers serves to improve transparency, not just within supply chain but also externally from the perspective of regulators and investors (see, e.g., Kim 2015; Wang et al. 2016). Several other approaches to improve transparency have been explored in the literature, including (i) revealing the list of suppliers (Chen et al., 2019; Kalkanci and Plambeck, 2020b), (ii) sharing information about suppliers with consumers (Kraft et al., 2018), (iii) testing competitors' products to uncover violations (Plambeck and Taylor, 2019), and (iv) mandatory disclosure of noncompliance findings (Kalkanci and Plambeck, 2020a; Zhang et al., 2019).

Besides auditing, a variety of other means have been examined to improve socially responsible operations, including (i) buyers investing in supplier development (Mendoza and Clemen, 2013; Huang et al., 2017; Karaer et al., 2017; Lee and Li, 2018), (ii) imposing sustainability requirements in sourcing (Agrawal and Lee, 2019), (iii) cultivating a socially responsible supply base (Guo et al., 2016), (iv) supply-chain restructuring (Letizia and Hendrikse, 2016; Orsdemir et al., 2019), and (v) involving NGOs and NPOs (Kraft et al., 2013; Devalkar et al., 2017). We refer the reader to Lee and Tang (2018) for a discussion of recent developments and research opportunities in socially responsible operations.

### 2.3 Model

The supply network we consider consists of two buyers, and is depicted in Figure 2.1. Each buyer sources two distinct inputs – one each from two different suppliers – to assemble his end product. The two buyers are linked with each other in the network via a common supplier, who supplies to both the buyers. Without loss of generality, we assume that a buyer needs one unit each of the two inputs to assemble one unit of his end product.[2] Let $B_i, i \in \{1, 2\}$, denote the two buyers and $S_j, j \in \{1, c, 2\}$, denote the three suppliers; supplier $S_c$ is the common supplier, while suppliers $S_1$ and $S_2$ are the independent suppliers of buyers $B_1$ and $B_2$, respectively. Thus, we have a W-shaped network. To isolate the impact of a supplier's position in the network, we assume that all the suppliers are symmetric, except for their position in the network.

Our model is a two-stage game. In the first stage, the buyers simultaneously decide which suppliers to audit and the corresponding auditing efforts. In the second stage, after the uncertainty regarding the MWTP damages to the buyers from their suppliers' noncompliance of socially responsible practices is resolved, the buyers clear the downstream market. The sequence of events is shown in Figure 2.2 and is described in detail below.

- In stage 1, let the social-responsibility effort of each supplier be denoted by $e \in (0, 1)$; this corresponds to the probability that a supplier's operating practices comply with

[2] In general, if the ratio of the required inputs is $m : n$, we can define one procurement unit of the former (resp., latter) input as $m$ (resp., $n$) individual units, and the analysis carries through.

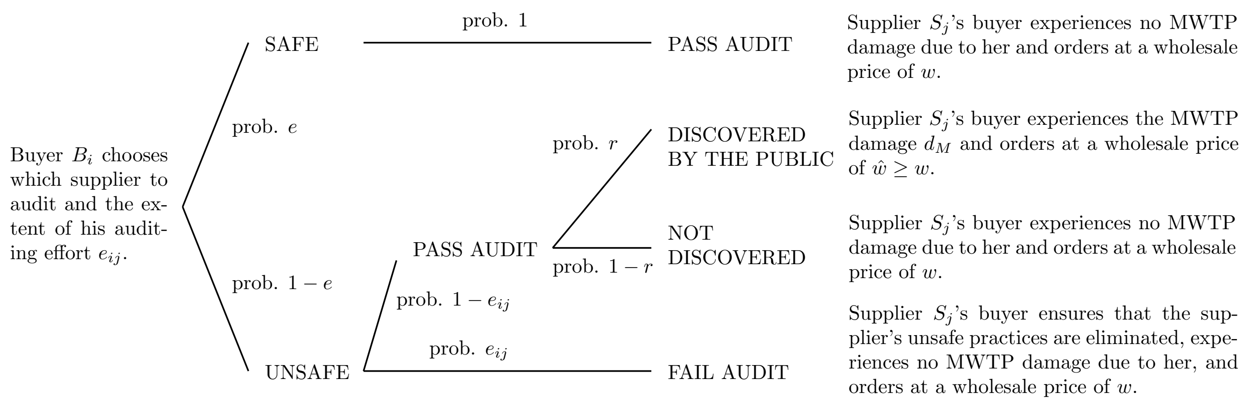


Figure 2.2. Sequence of Events

socially responsible standards. In other words, $e$ is the probability that a supplier is "safe", i.e., the supplier's practices are not socially harmful (Plambeck and Taylor, 2016). In order to focus on a supplier's position in the network, the social-responsibility efforts of the suppliers are assumed to be symmetric. The suppliers are assumed to be unintentionally *amoral*, in the sense that they do not endogenously decide their responsibility efforts in anticipation of the buyers' audits. This is common, especially in developing economies, in situations where the suppliers are unaware of social-responsibility standards or regulations due to, say, lack of education and/or communication, or ethical perception (Carroll, 1991, 2000). The scenario where the suppliers endogenously decide their responsibility efforts is discussed in Chapter 3.

We now discuss the auditing decisions of the buyers. The two buyers simultaneously choose which suppliers to audit and decide their respective auditing efforts. Let $e_{ij} \in [0,1]$ denote the effort buyer $B_i$ invests in auditing supplier $S_j$; $i \in \{1,2\}$ and $j \in \{1,c,2\}$. The cost corresponding to the effort $e_{ij}$ invested in auditing a supplier consists of two components: A fixed cost $K$, and a convex and increasing variable cost $K_a(e_{ij})$; we assume that $K_a(e_{ij}) = \frac{a}{2}(e_{ij})^2$, where $a > 0$ is a constant. Thus, the total cost incurred by buyer $B_i$ for an auditing effort of $e_{ij}$ equals $K\mathbb{1}_{e_{ij}>0} + \frac{a}{2}(e_{ij})^2$; similar cost functions have been used in Plambeck and Taylor (2016) and Fang and Cho (2020).

Naturally, a higher auditing effort implies that an unsafe supplier is more likely to be identified during the audit. To embody the practice of firms typically auditing only a subset of their suppliers due to resource constraints, we assume that a buyer, when auditing unilaterally, can audit at most one of his two suppliers. In Section 2.6, we show the robustness of our findings with respect to this assumption by analyzing an alternate model in which the buyers divide their limited auditing resources among their suppliers.

The suppliers' social-responsibility efforts and the buyers' auditing decisions can result in the following potential outcomes. If a supplier is safe, then she will pass an audit for sure and therefore will cause no MWTP damage to her buyer(s). If a supplier is unsafe but passes a buyer's audit (with probability $1 - e_{ij}$), then her unsafe practices may or may not be discovered in public. If discovered – with probability $r \in (0, 1]$, either through the media or through exposure from NGOs or other stakeholders – this identification results in an MWTP damage of $d_M > 0$ to the buyer(s) associated with this supplier. If not discovered, no MWTP damage incurs to the buyer who sources from the unsafe supplier. Thus, the *ex ante* likelihood that buyer $B_i$ faces the MWTP damage caused by the noncompliance of his independent supplier $S_i$ is $r(1-e)(1-e_{ii})$, and the *ex ante* likelihood that buyer $B_1$ ($B_2$) faces the MWTP damage caused by the noncompliance of the common supplier $S_c$ is $r(1 - e)(1 - e_{1c})(1 - e_{2c})$.

If an audit of a supplier reveals that the supplier is unsafe, then the buyer works with the supplier to ensure that the harmful practices are eliminated and the supplier is subsequently a safe one. This reflects the practice, followed by prominent buyers such as Apple, of helping unsafe suppliers improve compliance rather than terminating the business relationship. A supplier who is detected of having committed social-responsibility violations is placed on probation until she passes the next audit. During probation, the supplier implements a corrective action plan to enhance her responsibility effort. In some cases, the buyer may voluntarily disclose the identity of the supplier, which can also result in a loss of goodwill for the supplier (Apple, 2015). Let $\hat{d}_S$ denote the cost incurred by the supplier due to the identification of responsibility violations through an audit. In this case, however, the buyer does not suffer from any MWTP damage since the unsafe practices are eliminated before they are identified in public. Note that if the common supplier is identified as being unsafe by a buyer's audit, then the elimination of this supplier's harmful practices implies that the other buyer too will not suffer from the potential MWTP damage the common supplier could have caused. Also, as observed in Kalkanci et al. (2016), any voluntary disclosure by a buyer about his suppliers' unsafe practices avoids a negative impact on his demand as such an action helps retain consumers' trust.

- In stage 2, the buyers realize the MWTP damage. The buyers then order at an exogenous wholesale price of $w$ per unit if the corresponding supplier is not discovered as being non-compliant in public, or at an exogenous wholesale price $\hat{w} \geq w$ per unit otherwise, and clear the market (if $\hat{w} > w$, the interpretation is that the buyer switches to a backup supplier; if $\hat{w} = w$, the interpretation is that the buyer continues sourcing from the same supplier and lets the supplier address the discovered non-compliance issues, for which the supplier incurs a cost $d_S$).

To understand the potential inefficiency that can result from competition, we consider two scenarios: one where the buyers do not compete in the downstream market, and the other where they do. We model competition between the buyers as quantity competition in a single market with differentiated products. The buyers simultaneously decide their sourcing quantities $q_i$, $i \in \{1, 2\}$, from their respective suppliers, corresponding to their realized MWTP. The inverse demand function is $p_i = \alpha - q_i - \beta q_{i'}$

for buyer $B_i$ with no MWTP damage, and is $p_i = \alpha - d_M - q_i - \beta q_{i'}$ for buyer $B_i$ who experiences an MWTP damage of $d_M$, where $i, i' \in \{1, 2\}$, $i \neq i'$, and $\beta \in [0, 1]$. When $\beta = 0$, the two buyers do not compete; when $\beta \in (0, 1]$, they do. We note that this type of a generalized-quantity competition model was pioneered by Dixit (1979) and Singh and Vives (1984), and has also been applied in the Operations Management literature; see, e.g., Goyal and Netessine (2007) and Perakis and Sun (2014).

Let $\pi_i^b$, $i \in \{1, 2\}$, denote the *ex post* equilibrium profit of buyer $B_i$ in stage 2, and $\Pi_i^b$, $i \in \{1, 2\}$, denote the *ex ante* expected profit of buyer $B_i$. To ensure that the buyers order positive amounts from the suppliers, we assume that $(2 - \beta)\alpha - 2d_M > 2(1 - \beta)w + 2\hat{w}$, $(2 - \beta)(\alpha - d_M) > (4 - \beta)\hat{w} - \beta w$, and $\alpha - d_M > 2\hat{w}$; this implies that the MWTP damage that the buyers could potentially face is not severe enough to stop them from running their business.

Before proceeding further, we clarify the assumptions underlying the sequence of events in our model.

**Remark:** An underlying assumption of the setting of our model is that a buyer (say, $B_1$) and a supplier (say, $S_1$) already have an established prior relationship (through interactions for previous generations of the buyer's product). That is, from the viewpoint of the public, there is already an established "link" between $B_1$ and $S_1$ at the beginning of stage 1. Therefore, if $S_1$ is detected of a social-responsibility violation in public in stage 1, then $B_1$'s brand promptly suffers an MWTP damage in stage 2. In summary, under our assumed sequence of events, the buyers do not know the compliance status of their suppliers in stage 1 and make their auditing decisions in this stage. The compliance status of the suppliers gets revealed and the consequent MWTP damage (if any) to the buyers (who are linked to the exposed non-compliant suppliers) is realized at the end of stage 1. Then, the buyers make their ordering decisions in stage 2. ■

## 2.4 Analysis

To solve the two-stage problem, we use backward induction. In stage 2, there are five possible scenarios depending on the realized MWTP damage and the resulting wholesale prices: no damage to either buyer, no damage to one buyer and one supplier causing damage to the other buyer, one supplier causing damage to each buyer, one supplier causing damage to one buyer and two suppliers causing damage to the other, and two suppliers causing damage to each buyer. Lemma 2.4.1 summarizes the buyers' equilibrium sourcing quantities and profits under each of these outcomes, assuming that the number of suppliers causing the MWTP damage to buyer $B_2$ is greater than or equal to the corresponding number for buyer $B_1$; the other case is symmetric and is therefore omitted for brevity. We use these results in our subsequent analysis. The proofs of the technical results are in the appendices.

The equilibrium outcomes in stage 2 depend on the MWTP damage the buyers realize. The outcomes are symmetric for both the buyers in the following cases: (a) neither buyer incurs the damage, (b) one supplier of each buyer causes the damage, and (c) both suppliers of each buyer cause the damage. However, when the number of suppliers causing the damage is different for one buyer from that for the other buyer, the one with a higher number suffers more.

**Lemma 2.4.1. (Equilibrium *ex post* sourcing quantities and profits of the buyers).** *The equilibrium sourcing quantities and profits of the two buyers, corresponding to the five possible scenarios of the realized MWTP damage and the resulting wholesale prices, are as follows:*

| *Supplier Noncompliance Outcome* | *Equilibrium Sourcing Quantities* $(q_1^*, q_2^*)$ | *Equilibrium Profits* $(\pi_1^b, \pi_2^b)$ |
|---|---|---|
| *No damage to either buyer* | $\frac{\alpha-2w}{2+\beta}, \frac{\alpha-2w}{2+\beta}$ | $\left(\frac{\alpha-2w}{2+\beta}\right)^2, \left(\frac{\alpha-2w}{2+\beta}\right)^2$ |
| *No damage to buyer* $B_1$*; one supplier causing damage to buyer* $B_2$ | $\frac{\alpha}{2+\beta} + \frac{\beta d_M-(4-\beta)w+\beta\hat{w}}{4-\beta^2}$, $\frac{\alpha}{2+\beta} - \frac{2d_M+2(1-\beta)w+2\hat{w}}{4-\beta^2}$ | $\left(\frac{\alpha}{2+\beta} + \frac{\beta d_M-(4-\beta)w+\beta\hat{w}}{4-\beta^2}\right)^2$, $\left(\frac{\alpha}{2+\beta} - \frac{2d_M+2(1-\beta)w+2\hat{w}}{4-\beta^2}\right)^2$ |
| *One supplier causing damage to buyer* $B_1$*; one supplier causing damage to buyer* $B_2$ | $\frac{\alpha-d_M-w-\hat{w}}{2+\beta}, \frac{\alpha-d_M-w-\hat{w}}{2+\beta}$ | $\left(\frac{\alpha-d_M-w-\hat{w}}{2+\beta}\right)^2, \left(\frac{\alpha-d_M-w-\hat{w}}{2+\beta}\right)^2$ |
| *One supplier causing damage to buyer* $B_1$*; two suppliers causing damage to buyer* $B_2$ | $\frac{\alpha-d_M}{2+\beta} - \frac{2w+2(1-\beta)\hat{w}}{4-\beta^2}$, $\frac{\alpha-d_M}{2+\beta} - \frac{(4-\beta)\hat{w}-\beta w}{4-\beta^2}$ | $\left(\frac{\alpha-d_M}{2+\beta} - \frac{2w+2(1-\beta)\hat{w}}{4-\beta^2}\right)^2$, $\left(\frac{\alpha-d_M}{2+\beta} - \frac{(4-\beta)\hat{w}-\beta w}{4-\beta^2}\right)^2$ |
| *Two suppliers causing damage to each buyer* | $\frac{\alpha-d_M-2\hat{w}}{2+\beta}, \frac{\alpha-d_M-2\hat{w}}{2+\beta}$ | $\left(\frac{\alpha-d_M-2\hat{w}}{2+\beta}\right)^2, \left(\frac{\alpha-d_M-2\hat{w}}{2+\beta}\right)^2$ |

Recall that each supplier's (exogenous) responsibility effort is assumed to be the same (denoted by $e, 0 < e < 1$) in order to isolate the impact of a supplier's position in the network. The first-stage decision is a game between the two buyers, where each buyer $B_i$, $i \in \{1, 2\}$, decides who to audit and, simultaneously, how much effort to exert. If a buyer chooses not to audit a supplier, then her corresponding auditing effort is zero. When buyer $B_i$ audits supplier $S_j$; $j \in \{1, c, 2\}$, we assume that the buyer's equilibrium auditing effort $e_{ij}^*$ is in the interior of its domain (i.e., $e_{ij}^* \in (0, 1)$); see Appendix B.1 – similar assumptions have been made in the literature; see, e.g., Plambeck and Taylor (2016).

In stage 1, there are nine cases of auditing decisions of the two buyers: (case 1) each buyer audits his respective independent supplier; (cases 2 and 3) one buyer audits his independent supplier and the other audits the common supplier, and vice-versa; (case 4) both the buyers audit the common supplier; (case 5 and 6) one buyer audits his independent supplier and the other does not audit any of his suppliers; (case 7 and 8) one buyer audits the common supplier and the other does not audit any of his suppliers; (case 9) neither buyer audits any supplier. The expressions of the expected profit functions of the buyers under these cases are in Appendix B.2.

In the subsequent equilibrium analysis, when a buyer is indifferent between auditing a supplier and no-audit, we assume that the buyer chooses no-audit as a tie-breaking rule to eliminate non-essential equilibria when the auditing fixed cost equals a boundary threshold.

### 2.4.1 Benchmark: Unilateral Auditing Decisions When Buyers do not Compete

We first consider the benchmark case where the buyers do not compete, i.e., $\beta = 0$. The following result states the equilibrium auditing decisions of the buyers. Let

$$e_N^* \triangleq \frac{1}{4a} r(1-e) \left\{ \begin{array}{l} \left[1 - r(1-e)\right](\alpha - 2w)^2 - \left[1 - 2r(1-e)\right](\alpha - w - \hat{w} - d_M)^2 - \\ r(1-e)(\alpha - 2\hat{w} - d_M)^2 \end{array} \right\};$$

$$e_{NI}^* \triangleq \frac{1}{4a} r(1-e) \left\{ \begin{array}{l} \left[1 - r(1-e)\right](\alpha - 2w)^2 - \left[1 - 2r(1-e)\right](\alpha - w - \hat{w} - d_M)^2 - \\ r(1-e)(\alpha - 2\hat{w} - d_M)^2 \end{array} \right\} +$$

$$\frac{1}{16a^2}\left[r(1-e)\right]^3 \left\{ \begin{array}{l} \left[2(\alpha - 2w) - d_M\right] d_M + \\ 2(\hat{w} - w) \end{array} \right\} \left\{ \begin{array}{l} \left[1 - r(1-e)\right](\alpha - 2w)^2 - \\ r(1-e)(\alpha - 2\hat{w} - d_M)^2 - \\ \left[1 - 2r(1-e)\right](\alpha - w - \hat{w} - \\ d_M)^2 \end{array} \right\}.$$

**Proposition 2.4.1. (Unilateral auditing decisions when the buyers do not compete).** *There exists a threshold $K_u$ such that when the auditing fixed cost $K \geq K_u$, neither buyer audits any supplier, in equilibrium. When $K < K_u$, there exist two types of equilibria:*

*(A) Each buyer audits his independent supplier and each exerts an auditing effort of $e_N^*$.*

*(B) One buyer audits his independent supplier with an effort of $e_{NI}^*$ while the other buyer audits the common supplier with an effort of $e_N^*$.*

*Furthermore, equilibrium (B) is Pareto-dominant.*

The intuition is as follows: when the fixed cost incurred in auditing a supplier is too high, neither buyer wants to audit any supplier as auditing is simply too costly. When the fixed cost is not excessive, if one buyer chooses to audit his independent supplier, then the other buyer is indifferent between auditing his independent supplier and the common supplier, since the buyers do not compete and a buyer's sourcing quantity does not affect the market-clearing price realized by the other buyer. If one buyer chooses to audit the common supplier, the other buyer will want to audit his independent supplier to lower his social-responsibility risk (i.e., the probability of experiencing MWTP damage) and earn a higher profit.

Observe that while the auditing efforts are symmetric in equilibrium A, the effort invested in auditing the independent supplier is larger than that in auditing the common supplier in equilibrium B, i.e., $e_{NI}^* > e_N^*$. The intuition here is that the audit of the common supplier by one buyer also benefits the other buyer, resulting in an increase in the marginal profit of the latter with respect to his effort in auditing his independent supplier. Additionally, the latter equilibrium is Pareto-dominant due to the positive externality exerted by one buyer's audit of the common supplier on the other buyer's profit.

### 2.4.2 Unilateral Auditing Decisions When Buyers Compete

Next, we examine the case where the buyers compete, i.e., $\beta \in (0,1]$. The following result states the buyers' equilibrium auditing decisions. Let

$$e_I^* \triangleq \frac{4r(1-e)\left\{\begin{array}{l} \alpha(2-\beta)\Big\{\big[1-r(1-e)\big]d_M+\hat{w}-w\Big\}- \\ d_M w\big[1-2r(1-e)\big]\Big\{2-\beta\big[2-r(1-e)\big]\Big\}- \\ d_M\hat{w}\Big\{2-\beta r(1-e)\big[3-2r(1-e)\big]\Big\}- \\ {d_M}^2\big[1-r(1-e)\big]\big[1-\beta r(1-e)\big]- \\ (\hat{w}-w)\Big\{w\big[3-2\beta-2(1-\beta)r(1-e)\big]+\hat{w}\big[1+2(1-\beta)r(1-e)\big]\Big\} \end{array}\right\}}{\left\{\begin{array}{l} a(4-\beta^2)^2+ \\ 4\beta\big[r(1-e)\big]^2\Big\{\big[1-r(1-e)\big]{d_M}^2+2\big[1-r(1-e)\big](\hat{w}-w)d_M+(\hat{w}-w)^2\Big\} \end{array}\right\}}; \tag{2.1}$$

$$\hat{e}_I \triangleq \frac{4r(1-e)}{a(4-\beta^2)^2}\left\{\begin{array}{l} \alpha(2-\beta)\Big\{\big[1-r(1-e)\big]d_M+\hat{w}-w\Big\}- \\ d_M w\big[1-2r(1-e)\big]\Big\{2-\beta\big[2-r(1-e)\big]\Big\}- \\ d_M\hat{w}\Big\{2-\beta r(1-e)\big[3-2r(1-e)\big]\Big\}- \\ {d_M}^2\big[1-r(1-e)\big]\big[1-\beta r(1-e)\big]- \\ (\hat{w}-w)\Big\{w\big[3-2\beta-2(1-\beta)r(1-e)\big]+\hat{w}\big[1+2(1-\beta)r(1-e)\big]\Big\} \end{array}\right\}. \tag{2.2}$$

**Proposition 2.4.2. (Unilateral auditing decisions when the buyers compete).** *There exist three thresholds $K_u^L$, $K_u^M$, and $K_u^H$ such that:*

1. *If the auditing fixed cost $K < K_u^L$, then there exists a unique equilibrium in which the two buyers only audit their independent suppliers; each buyer exerts an auditing effort of $e_I^*$.*

2. *If* $K_u^L \leq K < K_u^M$*, then there exist two types of equilibria:*

   (i) *Each buyer audits his independent supplier with an effort of* $e_I^*$.

   (ii) *One buyer audits his independent supplier with an effort of* $\hat{e}_I$ *while the other buyer audits none of his suppliers.*

3. *If* $K_u^M \leq K < K_u^H$*, then, in the unique equilibrium, one buyer audits his independent supplier with an effort of* $\hat{e}_I$ *while the other buyer audits none of his suppliers.*

4. *If* $K \geq K_u^H$*, then, in the unique equilibrium, neither buyer audits any supplier.*

When the buyers compete in a single market with differentiated products, their sourcing quantities affect their market-clearing prices and, consequently, their profits. When the auditing fixed cost is small (i.e., $K < K_u^L$), if one buyer, say $B_1$, either does not audit any of his suppliers or audits his independent supplier, then $B_2$ chooses to audit his independent supplier instead of auditing the common supplier, to make himself more competitive. The explanation here is as follows: If $B_2$, instead, chooses to audit the common supplier and is able to uncover that supplier's unsafe practices and thereby eliminate them, then $B_1$ will not suffer from the potential MWTP damage that could have been caused by the common supplier, ultimately intensifying downstream competition. Thus, the audit of the common supplier by $B_2$ will essentially let $B_1$ free-ride at $B_2$'s expense. If one buyer chooses to audit the common supplier, then the other buyer still chooses to audit his independent supplier to maximally lower his social-responsibility risk. Thus, regardless of the supplier one buyer chooses to audit, the other buyer's best response is to audit his independent supplier. In equilibrium, both buyers audit their independent suppliers.

When the fixed cost is moderate (i.e., $K_u^L \leq K < K_u^M$), in addition to the above equilibrium, another one can sustain in which one buyer audits his independent supplier while the other does not audit any supplier. The reason here is that the marginal benefit to a buyer from auditing his independent supplier decreases in the other buyer's effort in auditing his independent supplier. If one buyer does not audit anyone, then the other buyer finds it profitable to audit his own independent supplier. However, when one buyer exerts a significant amount of effort ($\hat{e}_I$) to audit his independent supplier, the moderate fixed cost prohibits the other buyer from auditing either of his suppliers. The same intuition applies to the scenario where $K_u^M \leq K < K_u^H$.

When the fixed auditing cost is large enough (i.e., $K \geq K_u^H$), the buyers naturally prefer not to audit any supplier(s).

The main takeaway from Proposition 2.4.2 is that, in any equilibrium, the audited supplier(s), if any, is always an *independent* supplier. In other words, the common supplier, i.e., the one with higher centrality, is never audited in equilibrium. Comparing this to the Pareto-dominant equilibrium in Proposition 2.4.1 (where buyers do not compete), we understand the inefficiency resulting from competition: *While auditing the common supplier is better for the aggregate profit of the buyers, competition drives them away from auditing that supplier.*

### 2.4.3 Joint-Auditing Decisions

To mitigate the inefficiency observed under unilateral auditing, we now investigate the possibility of the buyers jointly auditing the suppliers via a *stable coalition*; as discussed in Section 2.1, there are several well-known instances of joint audits in practice. In our setting, when the two buying firms jointly audit the suppliers, the coalition functions as a single firm at the auditing stage; however, the two firms still compete in the downstream market. For the coalition to be stable, two conditions must be satisfied: (a) The aggregate profit of the coalition should be higher and (b) each firm should earn a higher profit, compared to the case where the two firms unilaterally make the auditing decisions.

We use $\boldsymbol{B^c} = \{B_1, B_2\}$ to denote the coalition, and $e_{cj}$ to denote the effort that the coalition decides to invest in auditing supplier $S_j, j \in \{1, c, 2\}$. The total cost incurred by the coalition for the auditing effort $e_{cj}$ equals $K\mathbb{1}_{e_{cj}>0} + \frac{a}{2}(e_{cj})^2$; in the same spirit as our earlier assumption that a buyer can audit at most one of his two suppliers due to resource constraints, we assume that the coalition can audit at most two of the three suppliers as the two buyers pool their resources together. If the coalition chooses to audit one independent supplier and the common supplier, we assume that $S_1$ is the independent supplier who is audited – the other case is symmetric. To fairly split the auditing cost between the buyers, we employ the notion of Shapley value and denote the share of buyer $B_i$ by $\Gamma_i$, $i \in \{1, 2\}$. The remainder of the setting remains the same as in the case where the firms do not cooperate in auditing.

Let $\pi^b(id_M, jd_M)$ denote the aggregate *ex post* profit of the buyers when buyer $B_1$ (resp., $B_2$) has $i$ (resp., $j$) suppliers who are identified in public as being socially irresponsible; $i, j \in \{0, 1, 2\}$. For our analysis here, we consider the scenario where the aggregate profit $\pi^b(0, 0) \geq \pi^b(d_M, 0) \geq \pi^b(d_M, d_M) \geq \pi^b(2d_M, d_M) \geq \pi^b(2d_M, 2d_M)$. That is, the aggregate profit of the buyers decreases as the sum of the number of their suppliers identified as being socially irresponsible increases.

The following proposition states the joint-auditing decisions of the buyers. Let $\Delta\Pi$ denote the difference between the expected profits of buyers $B_1$ and $B_2$ (excluding auditing costs).

**Proposition 2.4.3. (Optimal joint-auditing decisions and cost sharing).** *The coalition $\boldsymbol{B^c}$ is stable. Moreover, there exist thresholds $K_c^L$ and $K_c^H$ such that:*

1. *If the auditing fixed cost $K < K_c^L$, then jointly auditing the common supplier $S_c$ along with the independent supplier $S_1$ yields the highest aggregate profit for the buyers, i.e., the optimal auditing efforts $e^*_{c1} > 0, e^*_{cc} > 0, e^*_{c2} = 0$. In this case, the difference between the expected profits of buyers $B_1$ and $B_2$, $\Delta\Pi > 0$.*

2. *If $K_c^L \leq K < K_c^H$, then jointly auditing only the common supplier yields the highest aggregate profit for both the buyers, i.e., the optimal auditing efforts $e_{c1}^* = 0, e_{cc}^* > 0, e_{c2}^* = 0$. In this case, $\Delta\Pi = 0$.*

3. *If $K \geq K_c^H$, then the two buyers jointly audit none of the suppliers.*

*In cases (1) and (2), buyer $B_i$'s fair share $\Gamma_i$ of the auditing cost, which yields equal optimal expected profits for both the buyers, is as follows:*

$$\Gamma_1 = \frac{1}{2}\left[\sum_{j=1,c}\left[K\mathbb{1}_{e_{cj}^*>0} + \frac{a}{2}(e_{cj}^*)^2\right] + \Delta\Pi\right] \text{ and } \Gamma_2 = \frac{1}{2}\left[\sum_{j=1,c}\left[K\mathbb{1}_{e_{cj}^*>0} + \frac{a}{2}(e_{cj}^*)^2\right] - \Delta\Pi\right]. \tag{2.3}$$

The formation of a stable coalition to jointly audit the suppliers implies that both buyers earn higher profits relative to when they unilaterally audit only their respective independent suppliers. Notice that the common supplier $S_c$ is *always* audited by the coalition (unless the auditing fixed cost is prohibitively high, in which case no supplier is audited). Thus, joint-auditing fixes the inefficiency (namely, the common supplier is not audited) resulting from the competition between the buyers that we observed in Proposition 2.4.2.

In addition to auditing the common supplier $S_c$, the coalition may also audit the independent supplier $S_1$ when the auditing fixed cost is small enough. Doing so results in a lower total responsibility risk and, therefore, allows the coalition to achieve a higher total expected profit. On the surface, this seems to be a competitive advantage for buyer $B_1$, who directly sources from supplier $S_1$, in the second stage and correspondingly a disadvantage for buyer $B_2$. However, under the fair cost-sharing based on Shapley values, buyer $B_1$ also bears a larger portion of the auditing cost, as reflected by a positive $\Delta\Pi$; consequently, $\Gamma_1 > \Gamma_2$ in (2.3). Ultimately, both the buyers have the same expected profit.

When the fixed cost is moderate, the coalition only audits supplier $S_c$. In this case, the suppliers are symmetric from the perspective of both the buyers, and neither buyer gains a competitive advantage in the second stage. Therefore, the buyers simply split the auditing cost equally, as reflected by $\Delta\Pi = 0$; consequently, $\Gamma_1 = \Gamma_2$ in (2.3).

When the fixed cost is too high, it is intuitive that none of the suppliers should be audited.

We note that, in Proposition 2.4.3, it is possible for the coalition of buyers to jointly audit a supplier who does not supply to *both* the buyers in the coalition. There are indeed real-world instances of a buyer who, as part of a joint-auditing coalition, audits a supplier from whom he does not source. We discuss two examples below.

After the Rana Plaza tragedy, prominent garment brands signed the *2013 Accord on Fire and Building Safety* to jointly audit their collective set of suppliers in Bangladesh (Kasperkevic, 2016; Bangladesh Accord Foundation, 2018). Among the 1600 factories (suppliers) that are jointly monitored by these firms, only a subset supply to each firm. Further, suppliers typically vary in terms of the number of firms they supply to (Liu et al., 2019; Bangladesh Accord Foundation, 2016). Thus, there are many firms who jointly audit suppliers who they do not work with or jointly audit suppliers with low degree-centrality.

As another example, Vodafone, Orange, and fourteen other telecom operators have come together to create the Joint Audit Cooperation (JAC) for jointly auditing suppliers of the Information Communication Technology industry. Here too, we find that firms that are part of the JAC sometimes participate in auditing suppliers who do not supply to them. For example, Vodafone's website states: "...35 additional on-site assessments of suppliers within the industry were conducted jointly with other telecoms operators through JAC. Most of these related to the Vodafone supply chain" (Vodafone, 2015). This indicates that not all the suppliers jointly audited by Vodafone through the JAC are Vodafone's suppliers.

These two real-world examples support a similar possibility in our results on joint-auditing. In addition, notice that, in our analysis, when the coalition jointly audits the common supplier and an independent supplier, the buyer who sources from the audited independent supplier also bears a larger portion of the auditing cost – the allocation is based on the notion of Shapley value and is fair in a precise sense.

To summarize, the competition between the buyers conspires to make them audit only their respective independent suppliers (when they take their decisions unilaterally), thus avoiding the audit of the common supplier. However, by forming a stable coalition to jointly audit the suppliers and sharing the auditing cost fairly, both the buyers improve their profits. We note that prior work on joint-audits has typically considered settings in which multiple buyers source from one supplier; see, e.g., Caro et al. (2018) and Fang and Cho (2020). To our knowledge, the insight we obtain here – that *competition drives buyers away from suppliers with high centrality and joint-audit fixes this inefficiency* – has not been discussed in the literature.

Hitherto, we have focused on auditing decisions from the perspective of the buyers. In the next section, we view them through a social-planner's lens.

### 2.5 A Social-Planner's Perspective

Minimizing harm to society via the identification of socially irresponsible practices is arguably the most important goal a social planner (e.g., the government) would strive for. In this section, we examine the impact of joint-auditing on the social welfare, i.e., the sum of buyers' profits, suppliers' profits, and consumer surplus. For simplicity of exposition, we focus on the scenario where, if a supplier is discovered as being non-compliant in public, the buyer(s) continues sourcing from the same supplier. Recall from Section 2.3 that, under this scenario, a supplier who has been identified as being non-compliant in public incurs a cost $d_S$ to address her non-compliance and the corresponding buyer(s) orders at the same exogenous wholesale unit price $w$ (i.e., $\hat{w} = w$). The analysis for the alternate scenario where the buyer(s), instead, switches to a backup supplier, is similar and omitted for brevity.

Similar to the analysis in Section 2.4, in stage 2, there are five possible outcomes depending on the realized MWTP damage as well as the number of non-compliant suppliers discovered in public: no damage to either buyer, one independent supplier causing damage to one buyer (and no damage to the other buyer), the common supplier causing damage to both the buyers, two suppliers causing damage to both the buyers, and all three suppliers causing damage to both the buyers. Under each of these outcomes, the equilibrium *ex post* sourcing quantities $(q_1^*, q_2^*)$ and the profits of the buyers $\left(\pi_1^b, \pi_2^b\right)$ are shown in Lemma 2.4.1 (Section 2.4). For ease of exposition, we normalize the marginal production cost $c_p$ of a supplier to 0; the analysis remains the same if $c_p > 0$. Let the equilibrium *ex post* profit of supplier $S_j$ be denoted by $\pi_j^s$, $j \in \{1, c, 2\}$. We have:

$$\pi_c^s = \begin{cases} w(q_1^* + q_2^*), & \text{if supplier } S_c \text{ causes no MWTP damage,} \\ w(q_1^* + q_2^*) - d_S, & \text{otherwise.} \end{cases}$$

$$\pi_j^s = \begin{cases} wq_j^*, & \text{if supplier } S_j \text{ causes no MWTP damage}, j \in \{1, 2\}, \\ wq_j^* - d_S, & \text{otherwise.} \end{cases}$$

Let the equilibrium *ex post* consumer surplus be denoted by $\pi^c$. Following Dixit (1979), the consumer surplus underlying our quantity competition model (Section 2.3) is specified as follows, where the indicator $\mathbb{1}_i = 1$ if buyer $B_i$ experiences an MWTP damage and 0 otherwise:

$$\pi^c = (\alpha - d_M \mathbb{1}_1) q_1^* + (\alpha - d_M \mathbb{1}_2) q_2^* - \frac{1}{2} \left[ (q_1^*)^2 + 2\beta q_1^* q_2^* + (q_2^*)^2 \right] - \sum_{i=1}^{2} p_i q_i^*,$$

where $p_i$ is the market-clearing price of buyer $B_i$ with sourcing quantities $(q_1^*, q_2^*)$, i.e., $p_i = \alpha - d_M \mathbb{1}_i - q_i^* - \beta q_{i'}^*$; $i, i' \in \{1, 2\}$, $i \neq i'$.

Thus, the equilibrium *ex post* social welfare, which we denote by $\pi^{sw}$, is:

$$\pi^{sw} = \sum_{i \in \{1,2\}} \pi_i^b + \sum_{j \in \{1,c,2\}} \pi_j^s + \pi^c.$$

The following result summarizes the equilibrium social welfare under each of the five outcomes.

**Lemma 2.5.1. (Equilibrium *ex post* social welfare).** *The equilibrium social welfare corresponding to the five possible outcomes of the realized MWTP damage and the number of non-compliant suppliers discovered in public, are as follows:*

| *Supplier Noncompliance Outcome* | *Equilibrium Social Welfare* ($\pi^{sw}$) |
|---|---|
| *No damage to either buyer* | $\frac{2\alpha(\alpha-2w)}{2+\beta} - (\beta+1)\left(\frac{\alpha-2w}{2+\beta}\right)^2$ |
| *One independent supplier causing damage to one buyer* | $\frac{\alpha[2(\alpha-2w)-d_M]}{2+\beta} - d_M\left(\frac{\alpha-2w}{2+\beta} - \frac{2d_M}{4-\beta^2}\right) - d_S - \frac{1}{2}\left[\left(\frac{\alpha-2w}{2+\beta} + \frac{\beta d_M}{4-\beta^2}\right)^2 + 2\beta\left(\frac{\alpha-2w}{2+\beta} + \frac{\beta d_M}{4-\beta^2}\right)\left(\frac{\alpha-2w}{2+\beta} - \frac{2d_M}{4-\beta^2}\right) + \left(\frac{\alpha-2w}{2+\beta} - \frac{2d_M}{4-\beta^2}\right)^2\right]$ |
| *The common supplier causing damage to both the buyers* | $2(\alpha-d_M)\frac{\alpha-2w-d_M}{2+\beta} - d_S - (\beta+1)\left(\frac{\alpha-2w-d_M}{2+\beta}\right)^2$ |
| *Two suppliers causing damage to both the buyers* | $2(\alpha-d_M)\frac{\alpha-2w-d_M}{2+\beta} - 2d_S - (\beta+1)\left(\frac{\alpha-2w-d_M}{2+\beta}\right)^2$ |
| *All the three suppliers causing damage to both the buyers* | $2(\alpha-d_M)\frac{\alpha-2w-d_M}{2+\beta} - 3d_S - (\beta+1)\left(\frac{\alpha-2w-d_M}{2+\beta}\right)^2$ |

We note that the internal transfers between the consumers and the buyers, and those between the buyers and the suppliers, get cancelled in the *ex post* social welfare.

In stage 1, the buyers audit the suppliers – their decisions are as specified in Proposition 2.4.2 (unilateral auditing) and Proposition 2.4.3 (joint auditing). Three types of costs may be incurred in this stage: (1) the auditing cost of each buyer (or the coalition of the buyers), which is $K\mathbb{1}_{e_{ij}>0} + \frac{a}{2}(e_{ij})^2$ if buyer $B_i$ audits supplier $S_j$ with an auditing effort of $e_{ij}$, (2) the responsibility cost of a supplier, $\frac{b}{2}e^2$, where $e$ is her social-responsibility effort, and (3) the cost $\hat{d}_S$ incurred by a supplier due to the identification of her social-responsibility violations through an audit. With these costs incorporated, the expressions of the expected social welfare under unilateral and joint auditing are shown in Appendix B.3.

The following result identifies conditions under which joint auditing is socially beneficial relative to unilateral auditing. Specifically, if the fixed cost of auditing is not too high ($K < \min\{K_u^L, K_c^L\}$), market competition is not too intense (the substitution level between the buyers' end-products, $\beta < \frac{2}{3}$), and the cost to a supplier of public exposure of responsibility violations sufficiently exceeds the cost of their identification through an audit ($rd_S - \hat{d}_S$ exceeds a threshold), then the social welfare under joint auditing provably exceeds that under unilateral auditing. When one or more of these conditions do not hold, joint auditing may still be socially better than unilateral auditing; however, the precise comparison depends on the values of the problem parameters and is illustrated numerically below. Recall that the auditing effort of each independent supplier under unilateral auditing (Section 2.4.2) is $e_I^*$ and the auditing effort of the independent (resp., common) supplier under joint auditing (Section 2.4.3) is $e_{c1}^*$ (resp., $e_{cc}^*$).

**Proposition 2.5.1. (Comparison of the social welfare under unilateral and joint auditing).** *Assume that the auditing fixed cost $K < \min\{K_u^L, K_c^L\}$ and the substitution level between the buyers' end-products $\beta < \frac{2}{3}$. Then,*

*(i) The total auditing effort under joint auditing, namely $e_{c1}^* + e_{cc}^*$, is higher than the total auditing effort under unilateral auditing, namely $2e_I^*$.*

*(ii) There exists a threshold $\Delta_S$ such that if $rd_S - \hat{d}_S > \Delta_S$, then the social welfare under joint auditing is higher than that under unilateral auditing.*

Observe that the sufficient condition that determines the comparison between the social welfare under joint and unilateral auditing is characterized by the difference between the expected cost, $rd_S$, of addressing social-responsibility violations when identified in public and the cost, $\hat{d}_S$, of addressing these violations when discovered during an audit. We also note that the former is an expected cost because it is (potentially) incurred in stage 2, while the latter is (potentially) incurred in stage 1. This sufficient condition is likely to be satisfied in practice, since the public identification of social irresponsibility typically implies a significant loss of goodwill for a supplier. Since the total auditing effort is higher under joint auditing than that under unilateral auditing (part (i) of Proposition 2.5.1), the unsafe suppliers are less likely to incur the expected cost of $rd_S$ and more likely to incur the cost of $\hat{d}_S$ under joint-auditing, thus resulting in a higher social welfare relative to unilateral auditing.

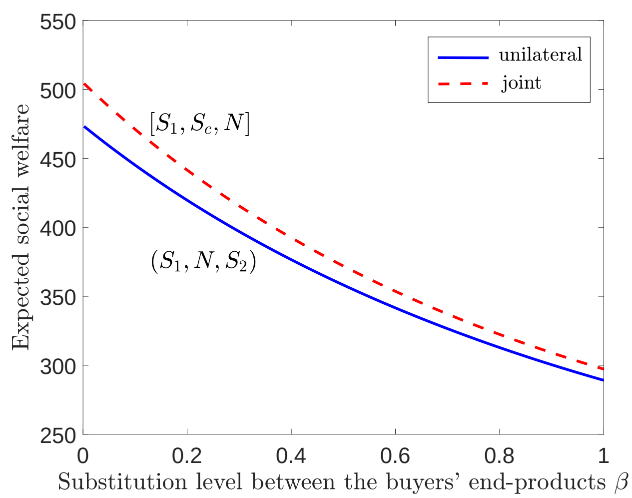


Figure 2.3. Joint auditing can be socially better than unilateral auditing even when the conditions of Proposition 2.5.1 are not satisfied: A numerical illustration.
*Note*: The parentheses (resp., square brackets) indicate the equilibrium auditing status of the three suppliers in the order $S_1$, $S_c$, and $S_2$, under unilateral auditing (resp., joint auditing). If a supplier is not audited, then we use $N$ to denote her auditing status. For example, $[S_1, S_c, N]$ indicates that suppliers $S_1$ and $S_c$ are audited and supplier $S_2$ is not audited.

Even when the conditions of Proposition 2.5.1 are not satisfied, the social welfare may be higher under joint auditing. An example is illustrated in Figure 2.3, where the condition on $\beta$

(the substitution level between the buyers' end-products) is violated. Here, the default values of the parameters are as follows: the supplier's responsibility effort, $e = 0.5$; the auditing fixed cost, $K = 0$; the auditing variable-cost parameter, $a = 30$; the social responsibility cost parameter, $b = 10$; the MWTP parameter, $\alpha = 30$; the MWTP damage, $d_M = 7$; the wholesale price, $w = 3$; the backup wholesale price, $\hat{w} = 3$; the cost to an unsafe supplier if identified through an audit, $\hat{d}_S = 1$; the public-discovery probability, $r = 0.5$; the cost to an unsafe supplier if discovered by public, $d_S = 2$.

To summarize, the primary policy implication of Proposition 2.5.1 is that *joint auditing leads to a higher social welfare, and should therefore be promoted by a social planner, in a scenario where the fixed cost of auditing is not too high, market competition is not too intense, and public exposure of social-responsibility violations is significantly more costly for a supplier than their identification via an audit.*

Appendix A discusses an alternate objective for the social planner, namely that of minimizing the probability of damage from social irresponsibility. Such an objective would be of interest to organizations such as the Environmental Protection Agency that primarily aim to protect human health and the environment.

### 2.6 Robustness Check: Allocating Auditing Resources Among Suppliers

Recall that our model in Section 2.3 assumed that, restrained by resource constraints, each buyer can audit at most one supplier when auditing unilaterally and the buyers can audit at most two suppliers when auditing jointly. To demonstrate the robustness of the insights revealed by our analysis thus far, we now examine an alternate setting in which each buyer, when auditing unilaterally, allocates his limited auditing resource among his two suppliers; when auditing jointly, the buyers pool their auditing resources and again allocate them among their three suppliers.

As in Section 2.3, let the social-responsibility effort of each supplier be denoted by $e \in (0,1)$. Each buyer $B_i$ has a limited resource $\bar{e}$ of auditing effort. When auditing unilaterally, the two buyers simultaneously decide how to allocate the effort $\bar{e}$ among their respective independent suppliers and the common supplier. Let $e_{ii}$ denote the effort buyer $B_i$ invests in auditing his independent supplier $S_i$, where $i \in \{1,2\}$; thus, his effort in auditing the common supplier $S_c$ is $e_{ic} = \bar{e} - e_{ii}$. The auditing variable cost incurred by buyer $B_i$ in auditing supplier $S_j$ with an effort of $e_{ij}$ is the same as before, i.e., $K_a(e_{ij}) = \frac{a}{2}\left(e_{ij}\right)^2$. For ease of analysis, we set the auditing fixed cost be 0 (i.e., $K = 0$). All other specifics, including the market clearance in stage 2, remain the same as in the earlier model. For expositional convenience in analyzing the joint-auditing case later, we assume that $\bar{e} \in (0, \frac{1}{2}]$ so that the total auditing resource owned by the two buyers is $2\bar{e} \in (0,1]$. We focus here on the scenario where the buyers compete, i.e., $\beta \in (0,1]$.

As before, we solve this game using backward induction. The buyers compete in stage 2; their *ex post* sourcing quantities and profits are the same as those in Lemma 2.4.1. In stage 1, under unilateral (resp., joint) auditing, the buyers simultaneously and unilaterally (resp., jointly) make their auditing decisions. The expressions for the buyers' profits are specified in Appendix B.2.

Using $e_{ic} = \bar{e} - e_{ii}$, we note that the strategy space of each buyer is a nonempty, compact, and convex subset of $\mathbb{R}$, and buyer $B_i$'s expected profit function, $i \in \{1,2\}$, is continuous and concave in his auditing effort $e_{ii}$. Therefore, from Theorem 1.2 of Fudenberg and Tirole (1991), there exists a pure-strategy Nash equilibrium in the auditing-resource-allocation decisions of the buyers. We formally state this observation below.

**Lemma 2.6.1. (Existence of an equilibrium).** *There exists a pure-strategy Nash equilibrium in the auditing decisions of the buyers when the buyers unilaterally audit the suppliers.*

The following result states the auditing decisions of the buyers under unilateral auditing.

**Proposition 2.6.1. (Unilateral auditing under allocation of limited auditing resources).** *Let* $\bar{e}_u = \frac{\beta[1-r(1-e)]}{(2-\beta)r(1-e)}$. *When the buyers audit unilaterally, there exists a threshold* $\alpha_u$ *such that, if the MWTP* $\alpha > \alpha_u$ *and each buyer's auditing resource* $\bar{e} < \bar{e}_u$, *then each buyer spends his entire auditing resource on his independent supplier, in equilibrium.*

The intuition behind this result is as follows: when competing buyers each have limited auditing resources, an increase in the MWTP leads to an increase in their marginal benefit with respect to their effort in auditing their respective independent suppliers. Consequently, when the auditing resources are scarce and the MWTP is large enough, the buyers invest these resources in their entirety in auditing their respective independent suppliers to maximize their benefit under competition. Thus, the observation here under unilateral auditing echoes our finding in Section 2.3: when auditing unilaterally, the buyers – driven by competition – focus on auditing their independent suppliers.

Next, as in Section 2.3, we show (in Proposition 2.6.2 below) that joint auditing fixes this inefficiency. Recall that, in stage 1, the buyers now jointly possess a pooled auditing resource of $2\bar{e} \in (0, 1]$ and allocate this resource among their three suppliers. Let $e_{cj} \in [0, 1]$ denote the effort invested by the coalition in jointly auditing the independent suppliers $S_j$, $j \in \{1, 2\}$. Thus, the effort in auditing the common supplier $S_c$ is $e_{cc} = 2\bar{e} - e_{c1} - e_{c2}$. The auditing variable cost is the same as that under unilateral auditing. As before, the buyers compete in the downstream market in stage 2.

Proposition 2.6.2 and Corollary 2.6.1 assume that the coalition's profit is jointly concave in the auditing efforts $(e_{c1}, e_{c2})$ of the two buyers – this is guaranteed by a sufficiently convex auditing cost and a sufficiently large MWTP; the precise conditions are derived in Appendix B.4.

**Proposition 2.6.2. (Joint auditing under allocation of limited, pooled auditing resources).** *Let* $\bar{e}_c = \frac{1-r(1-e)}{2r(1-e)}$. *When the buyers audit jointly, there exists a threshold*

*$\alpha_c$ such that, if the MWTP $\alpha > \alpha_c$ and each buyer's auditing resource $\bar{e} < \bar{e}_c$, then the buyers allocate a positive amount of their pooled auditing resource to the common supplier, in equilibrium.*

The intuition here is that, under joint auditing, when the pooled auditing resource is limited, an increase in the MWTP leads to an increase in the buyers' marginal aggregate profit with respect to their effort in auditing the common supplier, since the audit of that supplier benefits *both* the buyers. Therefore, when the MWTP is large enough, they prefer to audit the common supplier.

Propositions 2.6.1 and 2.6.2 imply the following result, which is consistent with our conclusion in Section 2.3.

**Corollary 2.6.1. (Comparing buyers' decisions under unilateral and joint auditing).** *Let $\hat{\alpha} = \max\{\alpha_u, \alpha_c\}$ and $\hat{e} = \min\{\bar{e}_u, \bar{e}_c\}$. If the MWTP $\alpha > \hat{\alpha}$ and each buyer's auditing resource $\bar{e} < \hat{e}$, then the buyers allocate all auditing resources to their independent suppliers under unilateral auditing and allocate a positive amount of their pooled auditing resource to the common supplier under joint auditing.*

## 2.7 Concluding Remarks

In supply networks consisting of multiple buyers and multiple suppliers, our attempt in this paper has been to understand the auditing decisions of the buyers aimed at identifying violations of socially responsible practices by their suppliers. Broadly, we have two main messages: (i) individual incentives can lead the buyers to de-prioritize the auditing of structurally-important suppliers (in our case, those with higher degree centrality), despite the auditing of these suppliers being better for the aggregate profit of the buyers; (ii) the practice of joint-auditing, where the buyers form a stable coalition to make auditing decisions and share the corresponding costs fairly among them, can correct this inefficiency.

An assumption we make in our analysis is that the structure of the supply network (i.e., the links between the buyers and the suppliers they source from) is well-established when the buyers make their auditing decisions. An alternate setting that future work can consider is one where the buyers simultaneously choose their suppliers, decide order quantities, and make auditing decisions.

In multi-tier supply networks, where suppliers in one tier of the network play the role of buyers in the next (upstream) tier, the entities that make auditing decisions can change across the tiers. For instance, while it is best for the downstream buyers to decide which of their primary suppliers to audit for socially responsible operations, it is preferable to in turn let the primary suppliers decide who among their suppliers (i.e., the secondary suppliers) they should audit. For obvious reasons these tier-wise decisions cannot be treated as independent, thus giving rise to a complex setting that we suggest for analysis in future investigations. Further, for a setting as involved as this, the design of incentives to ensure cooperation in auditing decisions at all tiers of the network is also a challenging quest.

# CHAPTER 3

# SUPPLIER CENTRALITY AND AUDITING PRIORITY IN SOCIALLY RESPONSIBLE SUPPLY CHAINS: ENDOGENOUS RESPONSIBILITY EFFORTS OF THE SUPPLIERS[1]

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In chapter 2, we considered the scenario where the suppliers are *amoral*, in the sense that they do not endogenously decide their responsibility efforts in anticipation of the buyers' audits. In this chapter, we discuss the scenario where the suppliers endogenously decide their responsibility efforts.

### 3.1 Analysis

Endogenizing the responsibility efforts of the suppliers introduces another layer of analytical complexity to the model in Section 2.3, since the three suppliers also become decision-makers in addition to the two buyers. That is, in stage 1, supplier $S_j$ simultaneously determines her responsibility effort, $e^r_j$, $j \in \{1, c, 2\}$, and incurs a convex and increasing responsibility-effort cost $K_r(e^r_j) = \frac{b}{2}(e^r_j)^2$, $b > 0$; a similar form for this cost has been used in Plambeck and Taylor (2016).

We note that the existence of equilibria cannot be guaranteed in general since the strategy space of the buyers is not convex. To maintain the tractability of the analysis, we assume that (a) $\beta = 1$ in the competition model of Section 2.3; and (b) when an unsafe supplier is identified in public, the corresponding buyer(s) allows that supplier to address noncompliance issues (for which the supplier incurs a cost $d_S$; see Section 2.3) and continues sourcing from that supplier at the wholesale price $w$. The remainder of the setting remains the same as the model in Section 2.3. We show in this section that the insights obtained from the earlier model continue to hold.

Our analysis utilizes the best response functions of the players. Therefore, it suffices to consider the following four cases of auditing decisions of the buyers: (case 1) each buyer audits his respective independent supplier; (cases 2 and 3) one buyer audits his independent supplier and the other audits the common supplier, and vice-versa; (case 4) both the buyers audit the common supplier. The expected profit functions of the buyers and suppliers are provided in Appendix C. Similar to the assumption pertaining to buyers' auditing efforts in Section 2.3, we assume that supplier $S_j$'s best-response responsibility effort $e_j^{r*}$ is in the interior of its domain; i.e., $e_j^{r*} \in (0, 1)$. The technical condition that guarantees this assumption is specified in Appendix C.

In what follows, we establish structural results on the strategic interaction among the buyers and the suppliers. We first explore how a buyer's audit of a supplier affects the supplier's responsibility efforts. Recall that $\hat{d}_S$ is the additional cost incurred by a supplier due to the identification of responsibility violations through an audit.

**Proposition 3.1.1. (Effectiveness of a buyer's audit)** *There exists a threshold $\bar{d}_S$ such that if $\hat{d}_S > \bar{d}_S$, the buyer's audit is effective, i.e., an increase in a buyer's auditing effort induces an increase in the responsibility effort of the supplier who is audited.*

Intuitively, a higher auditing effort should induce a higher responsibility effort by the supplier who is audited. Interestingly, if the additional cost from being found unsafe is too small, the buyer's auditing effort become a *substitute* for the supplier's responsibility effort, in the sense that the supplier simply relies on the buyer's audit to identify and address any unsafe practices, thereby negating one important purpose of an audit, namely to induce the suppliers to exert high responsibility effort. Only when the additional cost is large enough does the supplier increase her responsibility effort in response to a higher auditing effort.

Next, we examine the relationship between the efforts of the suppliers associated with a buyer.

**Proposition 3.1.2. (Complementarity of suppliers' efforts)** *The responsibility efforts of the two suppliers who are associated with the same buyer are complementary. That is, the best-response effort of one of these suppliers increases in the effort of the other supplier.*

The intuition here is as follows: If the responsibility effort of one of the suppliers of a buyer increases, then the expected MWTP damage for the buyer decreases and his expected sourcing quantity increases. This, in turn, leads to an increase in the other supplier's marginal profit with respect to her responsibility effort. Consequently, the other supplier increases her best-response effort to improve her profit. Thus, the best-response efforts of the two suppliers complement each other.

The next two results identify the auditing decisions that never arise in an equilibrium: the first corresponds to the case where the buyers unilaterally audit their suppliers while the second corresponds to the case where the buyers jointly audit their suppliers. In obtaining these results, we assume the condition identified in Proposition 3.1.1 under which auditing is effective, i.e., $\hat{d}_S > \overline{d}_S$.

**Proposition 3.1.3. (Equilibrium auditing decisions when buyers audit unilaterally)** *When the two buyers unilaterally make their auditing decisions, the audit of the common supplier never occurs in equilibrium. That is, in any equilibrium where suppliers are audited, only independent suppliers are audited.*

Consistent with our earlier results for the setting where suppliers' responsibility efforts are exogenous, one buyer auditing the common supplier and the other auditing his independent supplier, or both auditing the common supplier, is not an equilibrium when the buyers decide unilaterally. Here, as the responsibility efforts can be adjusted, the supplier being audited has a relatively higher effort than the one who is not. If one buyer audits the common supplier and the other audits his independent supplier, the buyer who audits the common one has an incentive to deviate to audit his independent supplier who has a lower responsibility effort, to lower his own social-responsibility risk. Similarly, if both buyers audit the common supplier, each has an incentive to deviate to audit his independent supplier because the independent suppliers have relatively lower responsibility efforts. In addition, since the two buyers compete, their sourcing quantities affect the market-clearing price and their profits, and it follows that the audit of the common supplier by one buyer makes him less competitive. Consequently, the audit of the common supplier never occurs in equilibrium.

Next, to resolve the inefficiency caused by the competition between the two downstream buyers, we again examine the possibility of the two buyers making auditing decisions jointly.

**Proposition 3.1.4. (Equilibrium auditing decisions when buyers jointly audit)** *When the two buyers jointly audit their suppliers, the audit of only the independent suppliers never occurs in equilibrium. That is, in any equilibrium where suppliers are audited, the common supplier is audited.*

The intuition is as follows: If the two buyers jointly audit an independent supplier, they have an incentive to deviate to audit the common supplier who has a lower responsibility effort, since auditing the common supplier not only benefits their aggregate profit but also lowers their social-responsibility risk. Similarly, if the buyers jointly audit the two independent suppliers, they have an incentive to deviate to audit the common supplier and an independent one because the common supplier has a lower responsibility effort and auditing her is beneficial for their aggregate profit.

The observations in Propositions 3.1.3 and 3.1.4 are consistent with our earlier findings in the case where the suppliers' responsibility efforts are exogenous, attesting to the robustness of the insight that while competition drives the buyers away from auditing their common supplier, joint-audit fixes this inefficiency.

# CHAPTER 4

# THE BEHAVIORAL PERIL OF LOW COST SOURCING

## 4.1 Introduction

In August 2019, the Business Roundtable, a group of CEOs of nearly 200 major U.S. corporations, issued a statement with a new definition of the "purpose of a corporation", which drops the age-old notion to first and foremost maximize the profit (Fitzgerald, 2019). One of the new goals, dealing fairly and ethically with their suppliers, is of importance in a socially responsible supply chain, where the suppliers are typically located in developing countries and it is costly for these suppliers to invest in efforts to improve social responsibility. The lack of such efforts of the suppliers may lead to noncompliance of socially responsible standards such as environmental pollution and deployment of child labor. Such noncompliance, if identified in public, may significantly damage the buyer's brand and consequently reduce the demand as well as the supply chain surplus (Plambeck and Taylor, 2016; Fang and Cho, 2020; Chen et al., 2020).

It is commonly believed that suppliers do not exert much effort to improve their social responsibility because their profit margins were barely enough to sustain the business (Plambeck and Taylor, 2016; Cho et al., 2019). Therefore, besides auditing and monitoring the suppliers, paying higher wholesale prices has been suggested as a method to improve suppliers' social responsibility (Jacoby, 2018). Interestingly, Plambeck and Taylor (2016) consider a game-theoretical model in a dyadic supply chain and find that, contradictory to this common view, under certain conditions, increasing buyer's wholesale price induces the supplier to put more efforts in hiding unsafe practices instead of improving social responsibility, which ultimately results in a lower profit of the buyer. Since suppliers' responsibility effort decisions are typically unobservable in practice, we design a lab experiment to test the counterintuitive theory as well as to explore the behavioral regularities involved in the decisions making. Through our experiment, we investigate the following research questions: *Will low cost sourcing (paying the low wholesale price to the supplier) improve 1) the supplier's responsibility effort, 2) the buyer's profit, and 3) the supply chain surplus? If there is any deviation from the theory, are there any behavioral regularities systematically affecting the decision making of the buyer and supplier?*

We design the experiment based on a stylized model which captures the key tradeoff in Plambeck and Taylor (2016). In the model, the buyer first decides whether to offer a low wholesale price or a high wholesale price to the supplier; after observing the wholesale price, the supplier then chooses between a low responsibility effort and a high responsibility effort to mitigate unsafe practices. In Appendix D.1, we provide an example of the parameter values in the model of Plambeck and Taylor (2016) that results in the payoffs in the stylized model. In alignment with the result of Plambeck and Taylor (2016), the unique subgame perfect Nash equilibrium of the stylized model is that the buyer pays the low wholesale price to the supplier and the supplier chooses the high responsibility effort, which results in the highest profit of the buyer and the highest supply chain surplus.

We then test the normative prediction based on the subgame perfect Nash equilibrium using a lab experiment with three treatments. Across the three treatments, our experimental design manipulates whether the buyer is a human, and if so, whether he/she makes active wholesale price decisions. In the experiment, each subject is assigned a fixed role either as a buyer or a supplier and then plays multiple rounds of the game. In each round, a buyer (automated or human) first offers the high wholesale price or the low wholesale price to the supplier [1]. The corresponding supplier then chooses between the low responsibility effort and the high responsibility effort, which then determines both players' payoffs.

[1]If the buyer is automated or does not make active price decisions, the price alternates automatically between high and low wholesale prices in two consecutive rounds.

We find that, when the buyers are automated or do not make active wholesale price decisions, consistent with the normative prediction, paying a low wholesale price leads to a more responsibility effort of the supplier, a higher profit of the buyer and a higher supply chain surplus. However, when human buyers make active price decisions, paying the low wholesale price to suppliers results in a higher profit of the buyer but not a more responsibility effort of the supplier or a higher supply chain surplus. To investigate such deviations, we divide the 15 cohorts in the treatment where buyers make active price decisions into two groups, based on the number of high wholesale price offered in each cohort. In one group, the buyers constantly pay the low price and the number of high price decisions in each cohort in all rounds is smaller than 5; in the other group, the number of high price decisions is larger than or equal to 5. In the group where the buyers constantly pay the low wholesale price, we find that suppliers react as if the price decisions are not made by human buyers (i.e. prices are set automatically in the system), and consistent with the normative prediction, paying the low wholesale price leads to a higher profit of the buyer and a higher supply chain surplus. In the other group, fewer suppliers choose the high responsibility effort when buyers pay the low wholesale price and more suppliers choose the high responsibility effort when buyers pay the high wholesale price. Therefore, paying the low wholesale price leads to a higher buyer's profit but a lower supply chain surplus, which is not consistent with the normative prediction.

We next investigate drivers of subjects' behavior to deviate from the normative predictions when buyers make active price decisions. We find that trust is a significant predictor for the deviation in both buyers' and suppliers' decisions. A more trusting buyer is more likely to pay the high wholesale price. A more trusting supplier is less (resp., more) likely to choose the high responsibility effort when human buyer offers the low (resp., high) wholesale price. In addition to trust, we also find that learning is significant in predicting suppliers' decisions: a supplier is less likely to choose high responsibility effort when offered low wholesale price as the observed proportion of buyers' decisions of high wholesale price increases.

In the next section we discuss the related literature. In Section 4.3, we present our experimental design and hypotheses. In Sections 4.4 and 4.5, we present our results and further discussions. In Section 4.6, we conclude with managerial implications.

## 4.2 Literature Review

Broadly speaking, our work falls within the literature on socially responsible supply chain management. Among the analytical work in this field, our work is related to papers studying a dyadic supply chain considering a wholesale price contract [2]. In particular, our setting is built on the framework of Plambeck and Taylor (2016), who consider a buyer sourcing from a supplier and find that under certain conditions, increasing wholesale price paid to the supplier decreases the supplier's social-responsibility effort and thus decreases buyer's profit. Cho et al. (2019) show that a manufacturer can offer a sufficiently high wholesale price to its supplier to deter the supplier's child labor employment if its inspections on employment of child labor are costly. Karaer et al. (2017) identify conditions about when it is effective for a buyer to offer a wholesale price premium to help improve a supplier's environmental performance. Building on the model of Plambeck and Taylor (2016), our work applies a behavioral lens to study buyer's and supplier's decision making and investigate how buyer's wholesale price decisions affect suppliers' responsibility efforts using a lab experiment.

Our paper also complements the emerging stream of behavioral operations management in socially responsible supply chains. Most of the work focuses on the interactions between customers and firms and studies the impact of supply chain transparency regarding social responsibility. To create supply chain transparency, a company may need to gain visibility

[2] Besides controlling wholesale price, there are several other methods in the literature that have been studied to improve social responsibility in a dyadic supply chain, such as, deferred payment (Babich and Tang, 2012), supplier certification, process audit, and contingency payment (Chen and Lee, 2017), sustainable sourcing policies (Agrawal and Lee, 2019), preventing supplier-auditor collusion (Chen et al., 2020), and buyer's investment in supplier's social responsibility capabilities under incomplete visibility (Kraft et al., 2020).

into its upstream suppliers and/or determine what information obtained via such visibility should be disclosed. Assuming full supply chain visibility and full disclosure of socially responsible information, Mahmoudzadeh and Siemsen (2019) study the impact of two types of consumer reactions – encouraging consumer reaction (customers' extra willingness-to-pay for responsibly sourced products) and discouraging one (customers' potential to boycott the firm in case of a supplier's social/environmental violation) – on a firm's responsible sourcing using behavioral models and experiments. Assuming full disclosure of socially responsible information, Kraft et al. (2018) find the conditions when consumers value greater supply chain visibility of a firm and thus benefit the firm's revenue. Assuming full supply chain visibility on social responsibility, Pigors and Rockenbach (2016) show different impacts of social responsibility in production on monopolistic supplier versus supplier competition: socially responsible productions decrease monopolistic supplier's profit because consumers are interested in cheap products, but increase the profits of the suppliers with higher levels of social responsibility in competition due to its positive influence on consumers' purchase decisions. Also assuming full supply chain visibility, Buell and Kalkanci (2020) study how transparency into internal and external responsibility initiatives affects customer perceptions and sales using both field and lab experiments. To study the impact of both supply chain visibility and disclosure of socially responsible information, Kalkanci et al. (2016) find that voluntary disclosure can receive more positive reaction from customers than mandatory disclosure and therefore increase the firm's market share. In a related work, Kraft et al. (2019) find that high supply chain visibility strengthens consumers' trust in a company's social responsibility communication.

There are much less work focusing on the inter-firm interactions in socially responsible supply chain. Zhang et al. (2019) focuses on the horizontal interactions among buying firms and test how initial catalyst of an alliance and status-seeking behavior affect the success of companies' formation of alliance in initiating a common fund to audit mineral suppliers. In contrast to the literature, we contribute to this emerging stream by studying the vertical interactions between a buyer and a supplier in a socially responsible supply chain and identifying behavioral regularities that affect the buyer's and supplier's behaviors.

Our paper is also related to behavioral operation management literature studying the role of trust and trustworthiness in supply chain management, for example, forecast information sharing (Özer et al., 2011, 2014; Spiliotopoulou, Donohue, and Gürbüz, Spiliotopoulou et al.; Özer and Zheng, 2017), relationship-specific investment (Beer et al., 2018), innovation sharing (Beer et al., 2019), procurement auction formats (Fugger et al., 2019), and high-ranking executives' decisions regarding forecast information sharing and inventory/capacity investment (Choi et al., 2020). We contribute to this stream by investigating a socially responsible supply chain and identify the role of trust in the buyer's and supplier's decision making.

## 4.3 Experimental Design and Hypothesis

### 4.3.1 Normative Prediction

We consider a two-stage stylized game in which a buyer sources a product from a supplier to capture the key tradeoff between the wholesale price of the buyer and the responsibility effort of the supplier in Plambeck and Taylor (2016). To simplify the decision making of the subjects, we reduce the decisions of both buyer and supplier to binary ones: in stage 1, the buyer decides whether to offer a *Low Price* or *High Price* to the supplier; in stage 2, after observing the price paid by the buyer, the supplier then chooses between *Low Effort* and *High Effort* to mitigate unsafe practices. The buyer's and the supplier's decisions jointly decide the final payoffs of the two players, which are representatives of the buyer and supplier's expected profits in Plambeck and Taylor (2016). Figure 4.1 presents the extensive form of the two-stage game graphically with the buyer's and the supplier's payoffs under each scenario. All information is common knowledge.

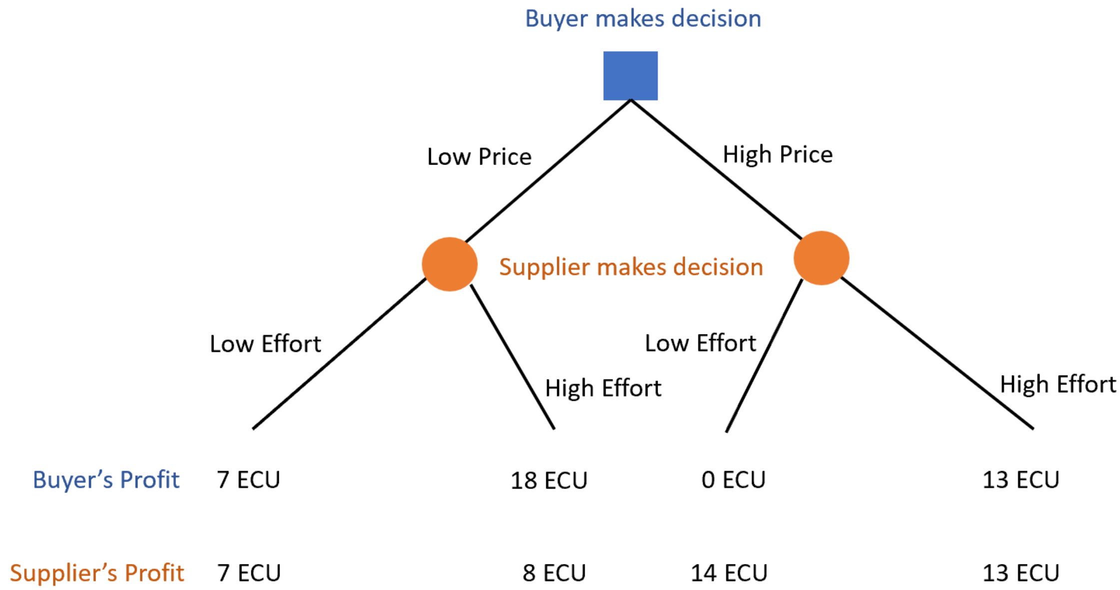


Figure 4.1. The Extensive Form of the Two-Stage Game
*Note*: ECU is the abbreviation of Experimental Currency Unit, which is the currency unit in the lab.

We solve the game by backward induction. In stage 2, if offered Low Price (resp., High Price), the supplier should choose the High Effort (Low Effort). To understand the rational, note that the Low Effort (resp., High Effort) in our model corresponds to the scenario where the supplier invests less (resp., more) effort in improving the socially responsible practice but more (resp., less) effort in hiding their irresponsible practice in Plambeck and Taylor (2016). In the scenario, if the supplier is offered a high wholesale price, it is optimal for the supplier to hide her irresponsible practice instead of investing in improving it. Anticipating the rational choice of the supplier, the buyer should offer Low Price in the first stage, resulting in a higher profit of the buyer, a higher responsibility effort of the supplier, and a higher supply chain surplus. To summarize, **the unique subgame perfect Nash equilibrium is that *the buyer chooses Low Price and then the supplier chooses High Effort***.

We make the following observations regarding the economic implications of the supplier's and buyer's decisions. We note that in the supply chain, the supplier's choice of responsibility efforts determines the supply chain surplus: if the supplier chooses High Effort (resp., Low Effort), the supply chain surplus is 26 (resp., 14). Also note that given the buyer's price decision, a supplier's choice of High Effort leads to a higher buyer's profit than that under the Low Effort.

The buyer's choice of the wholesale price decides how the supply chain surplus is divided between the two players (for a given responsibility effort decision of the supplier). When the buyer chooses Low Price, more supply chain surplus is allocated to himself, and his profit (7 or 18) is greater than or equal to the supplier's respective profit (7 or 8). When the buyer chooses to pay High Price, more supply chain surplus is allocated to the supplier, and his profit (0 or 13) is less than or equal to the supplier's respective profit (14 or 13).

### 4.3.2 Experimental Design

We conducted an experiment consisting of three treatments followed by one round of two additional tasks: an investment game (Berg et al., 1995; Beer et al., 2018) for measuring the subjects' trust and trustworthiness and a bomb task (Crosetto and Filippin, 2013) for measuring the subjects' risk attitudes.

#### Main Game

We design a lab experiment to test the counterintuitive theory prediction based on the unique subgame perfect Nash equilibrium. Since the wholesale price decisions and responsibility effort decisions are made by human managers, we attempt to elicit potential behavioral social preferences that may affect the decision making of the subjects via our experimental design.

Our experimental design manipulates whether the buyer is a human player, and if so, whether he/she makes active wholesale price decisions. There are three treatments: the *Computerized Buyers* treatment (CB), the *Dummy Human Buyers* treatment (DHB), and the *Active Human Buyers* treatment (AHB). In all the three treatments, the suppliers are always human subjects. In the CB treatment, the buyers are computerized, and the price decisions are set automatically, where Low Price is set in odd rounds and High Price is set in even rounds. In the DHB treatment, the buyers are human participants who do not make active decisions but receives profits. The wholesale price decisions are set automatically as in the CB treatment (Low Price in odd rounds and High Price in even rounds), the buyers receive profits based on the computerized wholesale prices and human suppliers' effort choices. In the AHB treatment, both the suppliers and the buyers are human participants who make active decisions, and both subjects receive profits according to their decisions. In the AHB treatment, we use the strategy method, by which human suppliers make conditional decisions for each possible scenario (human buyers offer High Price or Low Price) that may arise, in order to elicit suppliers' complete strategies [3]. Specifically, buyers are asked whether they want to pay High Price or Low Price to suppliers first, and then suppliers are asked which effort to choose if the buyer chose High Price, and if the buyer chose Low Price. The profits are calculated based on the buyer's wholesale price and the corresponding supplier's effort decision.

We conducted the experiments at a behavioral research laboratory. We implemented the experimental software using SoPHIE [4]. Subjects were students at a major public university in the United States and volunteered to participate through a web-based recruiting system.

Before the game started, the monitor read aloud the instructions, which was also available to the subjects, and then answered any clarification questions. Each subject had a computer to work with and made decisions on the provided computers. We recruited 30 participants

[3]We use the strategy method so that we can fully understand subjects' strategies in case a decision of buyers unlikely happens. The strategy method has been used in experimental economics literature. Brandts and Charness (2011) study on twenty-nine comparisons and find in no case a treatment effect found with the strategy method is not observed with the direct-response method.

[4]Software Platform for Human Interaction Experiments (https://www.sophielabs.com/).

(suppliers) for the CB treatment. All participants were assigned to the role of supplier and made decisions for 100 rounds. We recruited 30 participants for the DHB treatment and 90 participants for the AHB treatment. In these two treatments, each participant was randomly assigned a role of either a supplier or a buyer and kept the role for the entire duration of the game. The participants were grouped into cohorts of six (three suppliers and three buyers). Within each cohort, at the beginning of each round a supplier and a buyer were randomly matched together, replicating a one-shot game. The participants made decisions for 30 rounds. To mitigate reputation effects, subjects were unaware that their cohort size was 6 participants. They only knew that they would be randomly re-matched with someone else in the session. For the DHB treatment, since the human buyers do not make decisions, the decisions of each supplier are independent of the cohort. Therefore, we use the individual (human supplier) as the statistical unit of analysis. For the AHB treatment, we use the cohort as the main statistical unit of analysis because subjects were placed into a fixed cohort for an entire session. To summarize, there are 30 independent observations in the CB treatment, 15 in the DHB treatment and 15 in the AHB treatment. All the information about the game is common knowledge. For each round of the three treatments, a buyer (automated or human) first chose between Low Price and High Price. Then the corresponding supplier decided between Low Effort and High Effort. The payoff to each player was then realized and shown in a history table.

**Two Additional Tasks**

We measure the subjects' trust and trustworthiness in the investment game. There are two roles: senders and receivers. Both senders and receivers are endowed with 10 ECU. The sender can choose to send a portion of the endowment to the receiver. Any amount sent by the sender is tripled. The receiver then can choose to send back any amount up to the total amount received. We use the strategy method (Beer et al., 2018). Each subject decides how much to send as a sender and how much to return for each possible amount received as a receiver. Then the subjects are randomly assigned a role of either a sender or a receiver. A sender and a receiver are randomly matched together for payment based on their strategy decisions. We use the amount sent as a measure of subjects' trust level (ranged between 0 and 10) and use the difference between the maximum and minimum amounts subjects return as a measure of their trustworthiness (ranged between 0 and 30).

We measure the subjects' risk attitudes in the bomb task. There are 100 boxes on subjects' computer screen and there exists one bomb behind one of the 100 boxes. The probability of containing a bomb behind each box is the same (1%). Each subject's task is to choose the number of boxes to open by clicking on the corresponding boxes on the screen. After submitting the decisions, one will receive 0 ECU for payment if the bomb is contained in the boxes the subject chooses; one will earn a payoff of 0.2 ECU per box otherwise. We use the number of boxes that a subject opens as a measure of the risk-seeking level (ranged between 0 and 100). It implies that a risk neutral subject should choose 50 of boxes to open and a risk-averse (resp., risk-seeking) subject should choose a number smaller (resp., larger) than 50.

### 4.3.3 Hypothesis

With this experimental design we will formally test the following experimental hypotheses. The first hypothesis is derived from the normative prediction based on the unique subgame perfect Nash equilibrium.

**Hypothesis 1.** *Low cost sourcing (paying low wholesale price) will*

*1.a increase supplier's responsibility effort,*

*1.b increase buyer's profit, and*

*1.c increase supply chain surplus.*

However, social preferences may affect subjects' behaviors. One social preference that we take into consideration is the distributional fairness concerns. Other than simply maximizing profits, existing behavioral economics literatures have shown that people care about being treated fairly and possibly treating others fairly. Bolton and Ockenfels (2000) and Fehr and Schmidt (1999) developed models to explain inequity aversion in behavioral economics. Cooper and Kagel (2016) also provide a review of experimental literature on inequality aversion. In our CB treatment, there are no human buyers playing the game. So, there should be no social preference involved. In the DHB treatment, human buyers do not make any price decisions but receive payoffs. Because the only difference between the CB and DHB treatments is that the buyers who receive payoffs are human in the DHB treatment, suppliers with *outcome-based* distributional fairness concerns, given Low (resp., High) Price, will be more likely to choose Low (resp., High) Effort resulting in a fairer split of the supply chain surplus, even though choosing High (resp., Low) Effort will provide them a strictly higher profit in the DHB treatment.

**Hypothesis 2.** *If suppliers care about outcome-based distributional fairness,*

*2.a the proportion of suppliers' decisions of Low Effort when offered Low Price is higher in DHB treatment relative to that in CB treatment,*

*2.b the proportion of suppliers' decisions of High Effort when offered High Price is higher in DHB treatment relative to that in CB treatment.*

We also consider intention-based fairness concerns – trust and trustworthiness – as another two social preferences that may affect human's decision making. A general definition of trust is "a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another" (Rousseau et al., 1998). Trustworthiness is the fulfillment of the expectations. This definition is also used by Beer et al.

(2018) and Özer et al. (2011) in behavioral operations management. In our context, we specify the trust of a buyer as the buyer's willingness to believe in the reciprocal behavior of the supplier: a human buyer should offer High Price, if he believes that the supplier will reciprocate with High Effort when offered High Price, and the supplier may choose the Low Effort to penalize him when offered Low Price. Correspondingly, the trust of a supplier reflects her expectation about the buyer's behavior: a trusting supplier may expect her buyer to offer High Price. If she observes her buyer has chosen High Price, she may reward the buyer with High Effort. However, if she observes Low Price, she may penalize the buyer with Low Effort. We also specify trustworthiness as the supplier's willingness to choose High Effort when offered High Price, and to choose Low Effort when offered Low Price. Therefore, if trust affects subjects' decisions, we anticipate a positive correlation between buyers choosing High Price and their trusting levels, and a positive correlation between suppliers choosing High (resp. Low) Effort when offered High (resp. Low) Price and their trusting levels in AHB treatment. Moreover, if trustworthiness affects suppliers' decisions, we also expect to see a positive correlation between suppliers choosing High (resp. Low) Effort when offered High (resp. Low) Price and their trustworthiness level.

**Hypothesis 3.** *If trust affects subjects' decisions,*

- *3.a a more trusting buyer is more likely to choose High Price in AHB treatment,*
- *3.b a more trusting supplier is more likely to choose High Effort when offered High Price and more likely to choose Low Effort when offered Low Price in AHB treatment.*

**Hypothesis 4.** *If trustworthiness affects suppliers' decisions, a more trustworthy supplier is more likely to choose High Effort when offered High Price and more likely to choose Low Effort when offered Low Price in AHB treatment.*

## 4.4 Results

In Section 4.4.1, we test Hypothesis 1 and 2 by comparing suppliers' decisions of High Effort, buyers' average profit and average supply chain surplus across normative prediction and all three treatments. In Sections 4.4.2 and 4.4.3, we investigate the drivers for buyers' and suppliers' decisions and test Hypothesis 3 and 4, respectively. Unless otherwise noted, all hypothesis tests are two-tailed $t$-tests where a single cohort of six participants represents an independent observation in AHB treatment and each participant is treated as an independent observation in CB and DHB treatments. Regressions are run with random effects and clustered standard errors at the cohort level.

### 4.4.1 Overall Results

Hypothesis 1 predicts that paying low wholesale price will a) increase supplier's responsibility effort, b) increase buyer's profit, and c) increase supply chain surplus. Table 4.1, Table 4.2, and Table 4.3 report the average proportion of supplier's decision to choose High Effort, average buyers' profit and average supply chain surplus, respectively, if the buyer offered Low Price and if the buyer offered High Price in the three treatments. The tables present data calculated and aggregated at the independent observation level (individual human supplier average for CB and DHB and cohort average for AHB). Note that in the AHB treatment, we are able to calculate buyers' profits as well as supply chain surplus if the buyer offered Low Price and if the buyer offered High Price, in each round and for each buyer, with the strategy method to elicit suppliers' decisions.

In both the CB and DHB treatments in Table 4.1, consistent with the normative prediction, the proportion of suppliers' decisions of High Effort when buyers offer Low Price is higher than that when buyers offer High Price (CB: 0.664 versus 0.389, $p = 0.008$; DHB: 0.676 versus 0.236, $p = 0.003$).

Table 4.1. Suppliers' Decisions of High Effort in All Treatments

| **Treatment** | | **Average Proportion of Suppliers' Decisions of High Effort** | | ***t*-test (*p*-value)** |
|---|---|---|---|---|
| | | Low Price | High Price | Low Price vs High Price |
| CB | | 0.664 (0.370) | 0.389 (0.398) | 0.008 |
| DHB | | 0.676 (0.398) | 0.236 (0.354) | 0.003 |
| AHB | | 0.456 (0.205) | 0.515 (0.196) | 0.426 |
| ***t*-test (*p*-value)** | NP* vs CB | < 0.001 | < 0.001 | |
| | CB vs DHB | 0.924 | 0.212 | |
| | DHB vs AHB | 0.070 | 0.014 | |

(*NP: normative prediction of 100% High Effort when offered Low Price and 0% High Effort otherwise. Standard deviation reported in parenthesis.)

Comparing the CB treatment with the normative prediction, we observe that there is significant deviation of the proportion of suppliers' decisions of High Effort from the normative prediction of 100% High Effort when offered Low Price and 0% High Effort otherwise ($p < 0.001$). Such deviation results in significant difference between the buyers' average profit and the average supply chain surplus given Low Price or High Price with respect to the normative predictions (Table 4.2 and Table 4.3). The result implies that human subjects make errors in decision making.

Between the CB and DHB treatments, however, there is no significant difference of the proportion of suppliers' decisions of High Effort (Low Price: $p = 0.924$; High Price: $p = 0.212$), resulting in no significant differences of the buyers' average profit and the average supply chain surplus given Low Price or High Price (Table 4.2 and Table 4.3). The result implies that suppliers' decisions are not affected by whether the buyers are computers or

Table 4.2. Buyers' Average Profits in All Treatments

| **Treatment** | | **Buyers' Average Profit (ECU)** | | ***t*-test (*p*-value)** |
|---|---|---|---|---|
| | | Low Price | High Price | Low Price vs High Price |
| CB | | 14.304 (4.073) | 5.061 (5.174) | < 0.001 |
| DHB | | 14.431 (4.373) | 3.062 (4.596) | < 0.001 |
| AHB | | 12.011 (2.260) | 6.693 (2.552) | < 0.001 |
| ***t*-test (*p*-value)** | NP* vs CB | < 0.001 | < 0.001 | |
| | CB vs DHB | 0.924 | 0.212 | |
| | DHB vs AHB | 0.070 | 0.014 | |

(*NP: normative prediction of buyer's profit of 18 ECU when offered Low Price and 0 ECU otherwise. Standard deviation reported in parenthesis.)

Table 4.3. Average Supply Chain Surplus in All Treatments

| **Treatment** | | **Average Supply Chain Surplus (ECU)** | | ***t*-test (*p*-value)** |
|---|---|---|---|---|
| | | Low Price | High Price | Low Price vs High Price |
| CB | | 21.968 (4.443) | 18.672 (4.776) | 0.008 |
| DHB | | 22.107 (4.770) | 16.827 (4.243) | 0.003 |
| AHB | | 19.467 (2.466) | 20.178 (2.356) | 0.426 |
| ***t*-test (*p*-value)** | NP* vs CB | < 0.001 | < 0.001 | |
| | CB vs DHB | 0.924 | 0.212 | |
| | DHB vs AHB | 0.070 | 0.014 | |

(*NP: normative prediction of supply chain surplus of 26 ECU when offered Low Price and 14 ECU otherwise. Standard deviation reported in parenthesis.)

humans who do not make active decisions. Therefore, there are no significant outcome-based distributional fairness concerns of the suppliers involved in their decision making.

In the AHB treatment where the human buyers make active wholesale price decisions, the proportion of supplier's decisions of High Effort when buyers offer High Price is not significantly different from that when buyers offer Low Price (0.456 versus 0.515, $p = 0.426$). Moreover, between the DHB and AHB treatments, more suppliers deviate from the normative predictions in the AHB treatment: there are fewer suppliers choosing High Effort when buyers offer Low Price and more suppliers choosing High Effort when buyers offer High Price in AHB. Specifically, conditional on offering Low (resp., High) Price, the proportion of suppliers' decisions of High Effort is lower (resp., higher) in the AHB treatment than that in the DHB treatment (Low Price: 0.456 versus 0.676, $p = 0.070$: High Price: 0.515 versus 0.236, $p = 0.014$).

To summarize, Hypothesis 1.a – paying low wholesale price will increase supplier's responsibility effort – is supported in both the CB and DHB treatments, but not supported in the AHB treatment. Hypothesis 2 – suppliers' decisions are affected by outcome-based fairness concern – is not supported.

***Result 1****: Suppliers' decisions are prone to errors. There are no significant outcome-based distributional fairness concerns of the human suppliers involved in their decision making since there are no significant difference between their decisions in CB and DHB treatments. However, more suppliers deviate from the normative predictions in the AHB treatment than in the DHB treatment.*

We then analyze the buyers' profits shown in Table 4.2. In all treatments, consistent with the normative prediction, buyer's average profit when offering Low Price is higher than that when offering High Price (CB: 14.304 versus 5.061, $p < 0.001$; DHB: 14.431 versus 3.062, $p < 0.001$; AHB: 12.011 versus 6.693, $p < 0.001$). However, across DHB and AHB treatments, conditional on offering Low (resp., High) Price, buyer's average profit is lower (resp., higher) in the AHB treatment than that in the DHB treatment (Low Price: 12.011 versus 14.431, $p$ = 0.070; High Price: 6.693 versus 3.062, $p = 0.014$).

We next compare the supply chain surplus shown in Table 4.3. In both the CB and DHB treatments, average supply chain surplus when buyers offer Low Price is higher than that when buyers offer High Price (CB: 21.968 versus 18.672, $p = 0.008$; DHB: 22.107 versus 16.827, $p = 0.003$). In the AHB treatment, average supply chain surplus when buyers offer High Price is directionally higher but not significantly different from that when buyers offer Low Price (20.178 versus 19.467, $p = 0.426$). Additionally, across the DHB and AHB treatments, conditional on Low (resp., High) Price, average supply chain surplus is lower (resp., higher) in the AHB treatment than that in the DHB treatment (Low Price: 19.467 versus 22.107, $p = 0.070$; High Price: 20.178 versus 16.827, $p = 0.014$).

In summary, Hypothesis 1.b – paying low wholesale price will increase buyer's profit – is supported in all three treatments while Hypothesis 1.c – paying low wholesale price will increase supply chain surplus – is supported in both the CB and DHB treatments, but not in the AHB treatment.

***Result 2:*** *In all treatments, offering Low Price to the supplier results in a higher profit of the buyer. In CB and DHB, offering Low Price also results in a higher supply chain surplus. In AHB, however, offering Low Price does not result in a higher supply chain surplus.*

We next investigate the deviation from the normative prediction in the AHB treatment by digging into the buyers' decisions.

### Investigating the Impact of Buyers' Decisions in the AHB Treatment

In the AHB treatment, we have 45 human buyers. Each buyer makes decisions for 30 rounds. Among the 1350 total decisions, we find that 16.8% of them are High Price, which indicates that there is deviation of human buyers' decisions from the normative prediction where buyers should always choose Low Price. We then look at the human buyers' decisions in each of the 15 cohorts. Figure D.1 in the Appendix shows the stacked bar chart of buyers' decisions in each cohort. Among the 15 cohorts, we note that some of the cohorts have very low number of High Prices. To proceed, we divide the 15 cohorts into two groups based on the number of High Price offered in each cohort. In the one group, which we label as the *Constantly Low Price Group* (CLP Group), we have the cohorts with High Price decisions fewer than 5; in another group, which we label as *Non-Constantly Low Price Group* (NCLP Group), we have the cohorts with High Price decisions more than (or equal to) 5.

Table 4.4 summarizes the buyers' average profit and average supply chain surplus if the buyer offered Low Price and if the buyer offered High Price in CLP and NCLP Groups. For the 5 cohorts in CLP Group, consistent with the normative prediction and Hypothesis 1.b and 1.c, paying Low Price leads to a higher average profit for the buyer (13.600 versus 5.460, $p < 0.001$) and a higher average surplus for the supply chain (21.200 versus 19.040, $p = 0.074$). For the other 10 cohorts in NCLP Group, paying Low Price still leads to a higher average profit for buyer (11.217 versus 7.309, $p = 0.002$) but also a lower average supply chain surplus (18.600 versus 20.747, $p = 0.066$), which is not consistent with the normative prediction.

To understand the reasons behind the different results between the two groups, we compare the suppliers' reactions to price decisions of human buyers in CLP and NCLP Groups of the AHB treatment with the suppliers' reactions to automatic (with human buyers) price decisions in the DHB treatment. Table 4.5 summarizes the proportion of suppliers' decisions of High Effort if the buyer offered Low Price and if the buyer offered High Price in the DHB treatment and in CLP and NCLP Groups of AHB treatment. The proportion of suppliers' choosing High Effort in the CLP Group is not significantly different from that in the DHB treatment when offered Low Price or High Price (Low Price: 0.600 versus 0.676, $p = 0.530$; High Price: 0.420 versus 0.236, $p = 0.116$). This observation implies that even though in AHB treatment human buyers make active price decisions, when buyers have constantly

Table 4.4. Buyers' Average Profit and Average Supply Chain Surplus in CLP Group and NCLP Group [5]

| | **CLP Group (Number of High Price Decisions $< 5$)** | | **NCLP Group (Number of High Price Decisions $\geq 5$)** | |
|---|---|---|---|---|
| | Buyers' Average Profit (ECU) | Average Supply Chain Surplus (ECU) | Buyers' Average Profit (ECU) | Average Supply Chain Surplus (ECU) |
| Low Price | 13.600<br>(1.444) | 21.200<br>(1.575) | 11.217<br>(2.217) | 18.600<br>(2.419) |
| High Price | 5.460<br>(1.895) | 19.040<br>(1.750) | 7.309<br>(2.696) | 20.747<br>(2.489) |
| Low Price vs High Price<br>*t*-test (*p*-value) | $< 0.001$ | 0.074 | 0.002 | 0.066 |

(Number of observations: 5 cohorts in CLP Group and 10 cohorts in NCLP Group. Standard deviation reported in parentheses.)

chosen Low Price, suppliers react as if the price is set automatically in the DHB treatment. Thus, offering Low Price to supplier leads to a higher buyer's profit and a higher supply chain surplus. However, the proportion of suppliers' choosing High Effort in the NCLP Group is significantly lower than that in DHB treatment when offered Low Price (0.383 versus 0.676, $p = 0.024$) and significantly higher when offered High Price (0.562 versus 0.236, $p = 0.015$). That means, observing a higher chance to offer High Price by human buyers, fewer suppliers choose High Effort when buyers pay Low Price, and more suppliers choose High Effort when buyers pay High Price. Therefore, offering Low Price leads to a higher buyer's profit but a lower supply chain surplus.

[5] Our main findings are robust when the groups are divided by the cohorts with High Price decisions fewer than or more than 10. In particular, in the group with the cohorts where High Price decisions are more than (or equal to) 10, the average supply chain surplus is still lower when buyers offer Low Price than that when buyers offer High Price, and the difference is more significant ($p = 0.032$) than that in the group with the cohorts where High Price decisions are more than (or equal to) 5 ($p = 0.066$).

Table 4.5. Proportion of Suppliers' Decisions of High Effort in the DHB Treatment, CLP Group, and NCLP Group

| **Treatment** | | **Proportion of Suppliers' Decisions of High Effort** | |
|---|---|---|---|
| | | Low Price | High Price |
| DHB | | 0.676<br>(0.398) | 0.236<br>0.354 |
| CLP Group<br>(Number of High Price Decisions < 5) | | 0.600<br>(0.131) | 0.420<br>(0.146) |
| NCLP Group<br>(Number of High Price Decisions ≥ 5) | | 0.383<br>(0.202) | 0.562<br>(0.207) |
| $t$-test ($p$-value) | DHB vs CLP | 0.530 | 0.116 |
| | DHB vs NCLP | 0.024 | 0.015 |

(Number of observations: 5 cohorts in CLP Group and 10 cohorts in NCLP Group. Standard deviation reported in parentheses.)

In summary, while Hypothesis 1.c – paying low wholesale price will increase supply chain surplus – is not supported in the overall AHB treatment, it is supported within the CLP group of the AHB treatment. However, restricting attention to the NCLP group, an opposite result – paying low wholesale price will decrease supply chain surplus – is supported.

***Result 3***: *In AHB, when the buyer constantly only offers Low Price, the supplier makes effort decisions as if the buyer does not make active wholesale price decisions (as in the DHB treatment), and offering Low Price indeed increases the supply chain surplus. However, when the buyer does not constantly offer Low Price, then offering Low Price leads to a lower responsibility effort of the supplier and a lower supply chain surplus.*

### 4.4.2 Drivers for Buyers' Decisions in AHB Treatment

In this section, we investigate why human buyers may choose High Price even though they should have chosen Low Price according to normative prediction in the AHB treatment. To

Table 4.6. Impact of Trust and Round Number on Buyers' Decisions of High Price

| **Coefficients** | **Buyers' Decisions** |
|---|---|
| trust | 0.170** |
| | (0.081) |
| round | - 0.005 |
| | (0.019) |
| const | - 2.644*** |
| | (0.438) |

(Logit regression of each buyer's decisions of High Price for each round. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

analyze the factors affecting buyers' decisions, we run a logit regression of trust and round number on the decisions of each buyer for each round for all cohorts in the AHB treatment [6]. The trust and trustworthiness of each buyer is collected from the investment game (Berg et al., 1995) with one sender and one receiver. Both the sender and the receiver are endowed with a same amount of money. The sender can choose to send a portion of the endowment to the receiver. Any amount sent by the sender is tripled. The receiver then can choose to send back any amount up of the total amount received. We use the amount of the money sent as a measurement of subjects' trust and the difference between the maximum and minimum amounts subjects return as a measure of their trustworthiness. Table 4.6 summarizes the results. We find that, supporting Hypothesis 3.a, trusting level is a good predictor of buyers' decisions of High Price: a more trusting buyer is more likely to choose High Price.

To understand why the trusting levels of buyers correlate with their decisions, we note that a more trusting sender who believes his receiver will reciprocate with a higher return will send a higher amount of money to the receiver in the investment game. In our main

[6] As a robustness check, we also run the regression with NCLP Group (the 10 cohorts of AHB treatment where the number of High Price decisions is larger than or equal to 5) and obtain similar results. Table D.1 in Appendix D.2 summarizes the results.

game, the buyer decides to pay Low Price or High Price to the supplier and then the supplier chooses between Low Effort and High Effort. For a given price decision of the buyer, the supplier's choice of High Effort yields a higher profit of the buyer than the Low Effort. A more trusting buyer has a stronger belief that his supplier will reciprocate with his price decision: a supplier may choose the High Effort to reward him when offered High Price, and the supplier may choose the Low Effort to penalize him when offered Low Price. Therefore, such a buyer is more likely to choose High Price.

***Result 4***: *A more trusting human buyer is more likely to choose High Price.*

### 4.4.3 Drivers for Suppliers' Decisions in AHB Treatment

To investigate factors which make suppliers deviate from the normative prediction in the AHB treatment, we run a logit regression of trust, trustworthiness, round number and supplier's observed proportion of buyers' decisions of High Price on the decisions of each supplier for each round for all cohorts. Table 4.7 (resp., Table 4.8) summarizes the results on all cohorts of AHB treatment if buyers offered Low Price (resp., High Price) [7].

We find that the trusting level of the supplier is a significant factor in predicting suppliers' decisions: a more trusting supplier is more likely to choose Low (resp., High) Effort when offered Low (resp., High) Price, which supports Hypothesis 3.b – a more trusting supplier is more likely to choose High Effort when offered High Price and more likely to choose Low Effort when offered Low Price in AHB treatment. An explanation for the trust being a significant predictor is that a trusting supplier expects her buyer to be also trusting and thus to offer High Price. Therefore, when the trusting supplier observes her buyer has chosen High Price, she rewards the buyer with High Effort. Otherwise, she penalizes the buyer with Low Effort. In addition, although the coefficient of trustworthiness is directionally consistent with

[7] As a robustness check, we run the regression with the 10 cohorts in NCLP group of AHB treatment. Table D.2 and Table D.3 in Appendix D.2 summarize the results. The results are qualitatively similar.

Table 4.7. Impact of Trust, Trustworthiness, Round Number, and Observed Proportion of High Price on Suppliers' Decisions of High Effort Given Low Price (AHB)

| **Coefficients** | **Suppliers' Decisions** | **Suppliers' Decisions** | **Suppliers' Decisions** |
|---|---|---|---|
| trust | - 0.235* | | - 0.254* |
| | (0.121) | | (0.146) |
| trustworthiness | | - 0.008 | 0.017 |
| | | (0.052) | (0.064) |
| round | - 0.021* | - 0.019 | - 0.021* |
| | (0.012) | (0.012) | (0.012) |
| observed prop. of High Price | - 3.658** | - 3.565** | - 3.665** |
| | (1.464) | (1.455) | (1.483) |
| const | 1.489*** | 0.694 | 1.411** |
| | (0.508) | (0.516) | (0.552) |

(Logit regression of each supplier's decisions of High Effort given Low Price. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

Hypothesis 4 (in regressions where the trust variable is absent), it is not a significant factor. Therefore, Hypothesis 4 – trustworthiness affects suppliers' decisions – is not supported.

***Result 5****: When human buyer offers Low (resp., High) Price, a more trusting supplier is more likely to choose Low (resp., High) Effort.*

## 4.5 Discussion

In addition to the impact of buyers' trusting levels on their decisions, we also observe a positive correlation between the buyers' risk-seeking level and their decisions of High Price: A more risk-seeking buyer is more likely to choose High Price. Table D.4 and Table D.5 in Appendix D.2 present this result. This positive correlation can be explained by the uncertainty of suppliers' decisions and the human buyers' subjective beliefs of the corresponding suppliers' decisions given Low and High Price each round. Recall that in the AHB treatment,

Table 4.8. Impact of Trust, Trustworthiness, Round Number and Observed Proportion of High Price on Suppliers' Decisions of High Effort Given High Price (AHB)

| **Coefficients** | **Suppliers' Decisions** | **Suppliers' Decisions** | **Suppliers' Decisions** |
|---|---|---|---|
| trust | 0.281** | | 0.263* |
| | (0.127) | | (0.140) |
| trustworthiness | | 0.039 | 0.015 |
| | | (0.029) | (0.034) |
| round | 0.021 | 0.020 | 0.021 |
| | (0.013) | (0.012) | (0.013) |
| observed prop. of High Price | - 0.570 | - 0.718 | - 0.589 |
| | (0.984) | (1.004) | (0.952) |
| const | - 1.111* | - 0.461 | - 1.185* |
| | (0.612) | (0.411) | (0.603) |

(Logit regression of each supplier's decisions of High Effort given High Price. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

we find deviation of suppliers' decisions from the normative prediction: when human buyers make decisions in AHB treatment, comparing with the results in the DHB treatment, there are more suppliers choosing Low Effort when buyers offer Low Price and more suppliers choosing High Effort when buyers offer High Price. This observation of empirical probability distribution may affect the buyers' decisions. With the belief that there is a higher probability that his corresponding supplier will choose High Effort when offered High Price comparing with the case when offered Low Price, a risk-seeking buyer may end up paying High Price to the supplier for a higher expected utility.

We also find that learning (more specifically, the observed proportion of buyers' decisions of High Price) is significant in predicting suppliers' decisions in Table 4.7 and Table 4.8: a supplier is less likely to choose High Effort when offered Low Price as the observed proportion of High Price increases. The observation indicates that the buyer's commitment power to offer Low Price only is important to mitigate the deviation of the suppliers. If the buyer commits to constantly offer Low Price only as in the CLP Group, there should be less deviation of the suppliers to penalize the buyer to choose Low Effort when offered Low Price.

## 4.6 Conclusion

In a supply chain, the publicity of the noncompliance of social responsibility by suppliers can significantly damage their buying firms' brand and jeopardize the supply chain surplus. Plambeck and Taylor (2016) find a counter-intuitive result that under certain conditions, paying a higher wholesale price may lead to more efforts of the supplier in hiding unsafe practices instead of improving social responsibility. To test this finding, we design a lab experiment with three treatments based on a game that captures the fundamental tradeoff in Plambeck and Taylor (2016). The normative prediction based on the unique subgame perfect equilibrium is that the buyer pays the low wholesale price and the supplier chooses the more responsible action, which leads to the highest buyer's profit and a higher supply chain surplus.

We find evidence supporting the normative prediction when the buyers are automated or constantly offer the low wholesale price. However, when human buyers do not constantly offer low wholesale price, we find that offering a *high* wholesale price leads to a more responsibility effort of the supplier and a higher supply chain surplus, indicating potential Pareto-improvement opportunities for the entire supply chain.

We also investigate drivers of subjects' behavior to deviate from the normative predictions in the AHB treatment. We find that trust is a significant factor in predicting both buyers' and suppliers' decisions. A more trusting buyer is more likely to pay high wholesale price. A more trusting supplier is less (resp., more) likely to choose high responsibility effort when human buyer offers low (resp., high) wholesale price. Therefore, the prosocial behavior of trust leads to the behavioral peril of low cost sourcing in socially responsible supply chains: when the buyer pays low wholesale price, it results in a higher profit of the buyer, but a lower responsibility effort of the supplier and a lower supply chain surplus.

Our results have important managerial guidance for the buying firms seeking to create a socially responsible supply chain. Even in a setting that paying a low wholesale price should theoretically lead to a higher supplier's responsibility effort and a higher supply chain surplus, we find that paying a low wholesale price may lead to the opposite result due to the prosocial behavior of the players. On a higher level, our results echo the call of Business Roundtable (Fitzgerald, 2019) to deal fairly and ethically with their suppliers. For these firms who would like to pay high wholesale price to their suppliers, our results confirm that paying a high wholesale price will more likely lead to a higher responsibility effort of the suppliers and a higher supply chain surplus. Note that in our setting, the contract is a simple wholesale price contract. With more complicated contracts, by creating a higher supply chain surplus, it is possible that both the buyer and the supplier can be economically better off with an improved social responsibility of the supply chain.

# APPENDIX A

## AN ALTERNATE SOCIAL OBJECTIVE IN CHAPTER 2

In Section 2.5, we discussed the impact of joint auditing on social welfare. In this section, we discuss an alternate social objective, namely that of *minimizing the probability of damage from social-irresponsibility*, which we define as the probability that at least one of the suppliers is unsafe but is not discovered in the auditing process of the buyer(s). Let the equilibrium effort buyer $B_i$ invests in auditing supplier $S_j$ be $e^*_{ij}$. Recall from Section 2.3 that $e$ denotes the social-responsibility effort of each supplier. Thus, the probability of damage from social-irresponsibility under unilateral auditing is:

$$\gamma_u \triangleq 1 - e[1-(1-e)(1-e^*_{11})][1-(1-e)(1-e^*_{22})].$$

The probability of damage from social-irresponsibility under joint auditing, which we denote by $\gamma_c$, is defined analogously.

Among the parameters in our analysis, the probability $r$ of the public discovery of an unsafe supplier (i.e., the probability with which an unsafe supplier is detected in public) is one that can be naturally influenced by a social planner. For instance, the government can adjust its funding to public agencies or NGOs for conducting third-party audits, thereby affecting $r$. Note that the public-discovery probability $r$ affects the performance measures $\gamma_u$ and $\gamma_c$ through its impact on the equilibrium auditing efforts.

Figure A.1 is an illustrative plot of the impact of the public-discovery probability $r$ on the social-irresponsibility-damage probabilities $\gamma_u$ and $\gamma_c$.

For this figure, the default values of the parameters are as follows: the supplier's responsibility effort $e = 0.5$, the auditing fixed cost $K = 2$, the auditing variable-cost parameter $a = 30$, the MWTP parameter $\alpha = 30$, the MWTP damage $d_M = 7$, the wholesale price $w = 3$, the backup wholesale price $\hat{w} = 4$, and the substitution level between the buyers'

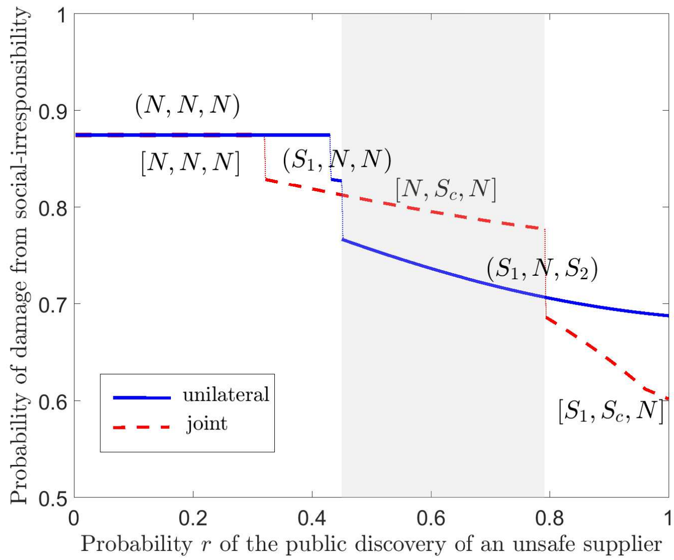


Figure A.1. Impact of the probability of the public discovery of an unsafe supplier on the probability of damage from social-irresponsibility, under unilateral auditing $\gamma_u$ (solid line) and joint auditing $\gamma_c$ (dashed line).
*Note*: The parentheses (resp., square brackets) indicate the equilibrium auditing status of the three suppliers in the order $S_1$, $S_c$, and $S_2$, under unilateral auditing (resp., joint auditing). If a supplier is not audited, then we use $N$ to denote her auditing status. For example, $[S_1, S_c, N]$ indicates that suppliers $S_1$ and $S_c$ are audited and supplier $S_2$ is not audited.

end-products $\beta = 1$. When there exist two equilibria under unilateral auditing (see Proposition 2.4.2), we use the equilibrium that results in a higher probability of damage from social-irresponsibility (using the other equilibrium does not change our conclusions). We make two observations from Figure A.1:

- As the public-discovery probability $r$ increases, both the social-irresponsibility-damage probabilities, namely $\gamma_u$ under unilateral auditing (solid line) and $\gamma_c$ under joint auditing (dashed line), decrease. Intuitively, the higher the chance of an unsafe supplier being discovered in public, the higher the chance that a buyer who sources from that supplier incurs the MWTP damage. Therefore, as $r$ increases, the buyers are incentivized to audit more suppliers or increase their auditing efforts when the number of audited suppliers remain the same.

- The second observation is more subtle: *joint-auditing may not necessarily lead to a lower probability of the damage from social-irresponsibility (relative to that under unilateral auditing).* Specifically, when the public-discovery probability $r$ is moderate (the grey region in Figure A.1), joint-auditing may result in a higher probability of damage from social-irresponsibility than that under unilateral auditing. To understand this observation, note that joint-auditing is more cost-effective for the buyers (relative to unilateral auditing) since the pooling of their resources enables them to make better decisions regarding which supplier(s) to audit and how much auditing effort to invest. Consequently, when the number of suppliers audited is the same or higher under joint auditing relative to unilateral auditing (in Figure A.1, this occurs when $r$ is small or large), joint-auditing results in a lower probability of damage from social-irresponsibility. However, it is also possible that the number of suppliers audited is *lower* under joint-auditing. In Figure A.1, this occurs in the region highlighted in grey – in this region, the buyers save auditing cost by only auditing the common supplier under joint-auditing while they audit their respective independent suppliers under unilateral auditing. Consequently, the probability of damage from social-irresponsibility is higher under joint-auditing since two of the three suppliers are not audited.

## APPENDIX B

## TECHNICAL ANALYSIS AND PROOFS IN CHAPTER 2

### B.1 Sufficient Conditions to Guarantee Interior Efforts

To ensure that the equilibrium auditing efforts are in the interior of their domain, we require that the auditing variable cost is sufficiently convex and the MWTP parameter is sufficiently large – that is, there exist thresholds $\bar{a}$ and $\bar{\alpha}$ such that $a > \bar{a}$ and $\alpha > \bar{\alpha}$. The closed-form expressions of the thresholds are algebraically cumbersome and, therefore, not specified here for brevity. In the special case where $\beta = 1$ and $\hat{w} = w$, we have $\bar{a} = \frac{d_M}{9}[2(\alpha - 2w) + 3d_M]$ and $\bar{\alpha} = 2w + \frac{5}{2}d_M$.

### B.2 Profit Functions of the Buyers

Given the auditing-effort vector $(e_{11}, e_{1c}, e_{22}, e_{2c})$, we denote the expected profit functions of buyers $B_1$ and $B_2$ by $\Pi_1^b(e_{11}, e_{1c}; e_{22}, e_{2c})$ and $\Pi_2^b(e_{22}, e_{2c}; e_{11}, e_{1c})$, respectively. When no confusion arises in doing so, we simplify this notation to $\Pi_1^b(e_{11}, e_{1c})$ and $\Pi_2^b(e_{22}, e_{2c})$, respectively. For the coalition $B^c$, we denote the aggregate profit of $B_1$ and $B_2$ by $\Pi^b(e_{c1}, e_{cc}, e_{c2})$. The expressions of the buyers' profits in the nine cases (see Section 2.3) can be obtained from the following generic profit expression by setting $e_{ij} = 0$ if supplier $S_j$ is not audited by buyer $B_i$. Using the notation $\lambda_I(e_{ij}) = r(1-e)(1-e_{ij})$ and $\lambda_C(e_{1c}, e_{2c}) = r(1-e)(1-e_{1c})(1-e_{2c})$, the expected profit of buyer $B_1$ is as follows. The expected profit of buyer $B_2$ is symmetric.

$$
\begin{aligned}
&\Pi_1^b(e_{11}, e_{1c}; e_{22}, e_{2c}) \\
=&\big[1-\lambda_I(e_{11})\big]\big[1-\lambda_C(e_{1c}, e_{2c})\big]\big[1-\lambda_I(e_{22})\big]\left(\frac{\alpha-2w}{2+\beta}\right)^2 + \\
&\big[1-\lambda_I(e_{11})\big]\big[1-\lambda_C(e_{1c}, e_{2c})\big]\lambda_I(e_{22})\left(\frac{\alpha}{2+\beta}+\frac{\beta d_M-(4-\beta)w+\beta\hat{w}}{4-\beta^2}\right)^2 + \\
&\lambda_I(e_{11})\big[1-\lambda_C(e_{1c}, e_{2c})\big]\big[1-\lambda_I(e_{22})\big]\left(\frac{\alpha}{2+\beta}-\frac{2d_M+2(1-\beta)w+2\hat{w}}{4-\beta^2}\right)^2 + \\
&\Big\{\big[1-\lambda_I(e_{11})\big]\lambda_C(e_{1c}, e_{2c})\big[1-\lambda_I(e_{22})\big] + \\
&\lambda_I(e_{11})\big[1-\lambda_C(e_{1c}, e_{2c})\big]\lambda_I(e_{22})\Big\}\left(\frac{\alpha-d_M-w-\hat{w}}{2+\beta}\right)^2 + \\
&\big[1-\lambda_I(e_{11})\big]\lambda_C(e_{1c}, e_{2c})\lambda_I(e_{22})\left(\frac{\alpha-d_M}{2+\beta}-\frac{2w+2(1-\beta)\hat{w}}{4-\beta^2}\right)^2 + \\
&\lambda_I(e_{11})\lambda_C(e_{1c}, e_{2c})\big[1-\lambda_I(e_{22})\big]\left(\frac{\alpha-d_M}{2+\beta}-\frac{(4-\beta)\hat{w}-\beta w}{4-\beta^2}\right)^2 + \\
&\lambda_I(e_{11})\lambda_C(e_{1c}, e_{2c})\lambda_I(e_{22})\left(\frac{\alpha-d_M-2\hat{w}}{2+\beta}\right)^2 - \left[K\mathbb{1}_{e_{11}>0}+\frac{a}{2}\left(e_{11}\right)^2\right] - \left[K\mathbb{1}_{e_{1c}>0}+\frac{a}{2}\left(e_{1c}\right)^2\right].
\end{aligned}
$$

### B.3 Equilibrium Social-Welfare Functions under Unilateral and Joint Auditing

Under unilateral auditing, given the auditing-effort vector $(e_{11}, e_{1c}, e_{22}, e_{2c})$, we denote the expected social-welfare function by $\Pi_u^{sw}(e_{11}, e_{1c}, e_{22}, e_{2c})$. Under joint auditing, given the auditing-effort vector $(e_{c1}, e_{cc}, e_{c2})$, we denote the expected social-welfare function by $\Pi_c^{sw}(e_{c1}, e_{cc}, e_{c2})$. Recalling that $\lambda_I(e_{ij}) = r(1-e)(1-e_{ij})$ and $\lambda_C(e_{1c}, e_{2c}) = r(1-e)(1-e_{1c})(1-e_{2c})$, the expected social-welfare function under unilateral auditing is:

$$
\begin{aligned}
&\Pi_u^{sw}(e_{11}, e_{1c}, e_{22}, e_{2c}) \\
=&\big[1-\lambda_I(e_{11})\big]\big[1-\lambda_C(e_{1c}, e_{2c})\big]\big[1-\lambda_I(e_{22})\big]\left[\frac{2\alpha(\alpha-2w)}{2+\beta}-(\beta+1)\left(\frac{\alpha-2w}{2+\beta}\right)^2\right]+ \\
&\big[1-\lambda_C(e_{1c}, e_{2c})\big]\Big\{\big[1-\lambda_I(e_{11})\big]\lambda_I(e_{22})+\lambda_I(e_{11})\big[1-\lambda_I(e_{22})\big]\Big\} \\
&\left\{\frac{\alpha\big[2(\alpha-2w)-d_M\big]}{2+\beta}-d_M\left(\frac{\alpha-2w}{2+\beta}-\frac{2d_M}{4-\beta^2}\right)-\frac{1}{2}\left[\left(\frac{\alpha-2w}{2+\beta}+\frac{\beta d_M}{4-\beta^2}\right)^2+\right.\right. \\
&\left.\left.2\beta\left(\frac{\alpha-2w}{2+\beta}+\frac{\beta d_M}{4-\beta^2}\right)\left(\frac{\alpha-2w}{2+\beta}-\frac{2d_M}{4-\beta^2}\right)+\left(\frac{\alpha-2w}{2+\beta}-\frac{2d_M}{4-\beta^2}\right)^2\right]\right\}+ \\
&\Big\{1-\big[1-\lambda_C(e_{1c}, e_{2c})\big]\big[1-\lambda_I(e_{11})\lambda_I(e_{22})\big]\Big\} \\
&\left[2(\alpha-d_M)\frac{\alpha-2w-d_M}{2+\beta}-(\beta+1)\left(\frac{\alpha-2w-d_M}{2+\beta}\right)^2\right]- \\
&\big[\lambda_I(e_{11})+\lambda_C(e_{1c}, e_{2c})+\lambda_I(e_{22})\big]d_S-(1-e)\big[e_{11}+1-(1-e_{1c})(1-e_{2c})+e_{22}\big]\hat{d}_S- \\
&\left[K\mathbb{1}_{e_{11}>0}+\frac{a}{2}\left(e_{11}\right)^2\right]-\left[K\mathbb{1}_{e_{1c}>0}+\frac{a}{2}\left(e_{1c}\right)^2\right]-\left[K\mathbb{1}_{e_{2c}>0}+\frac{a}{2}\left(e_{2c}\right)^2\right]- \\
&\left[K\mathbb{1}_{e_{22}>0}+\frac{a}{2}\left(e_{22}\right)^2\right]-\frac{3}{2}be^2. \qquad \text{(B.1)}
\end{aligned}
$$

The expected social-welfare function under joint auditing is:

$$
\begin{aligned}
&\Pi_c^{sw}(e_{c1}, e_{cc}, e_{c2}) \\
=&\big[1-\lambda_I(e_{c1})\big]\big[1-\lambda_I(e_{cc})\big]\big[1-\lambda_I(e_{c2})\big]\left[\frac{2\alpha(\alpha-2w)}{2+\beta}-(\beta+1)\left(\frac{\alpha-2w}{2+\beta}\right)^2\right]+ \\
&\big[1-\lambda_I(e_{cc})\big]\Big\{\big[1-\lambda_I(e_{c1})\big]\lambda_I(e_{c2})+\lambda_I(e_{c1})\big[1-\lambda_I(e_{c2})\big]\Big\} \\
&\left\{\frac{\alpha\big[2(\alpha-2w)-d_M\big]}{2+\beta}-d_M\left(\frac{\alpha-2w}{2+\beta}-\frac{2d_M}{4-\beta^2}\right)-\frac{1}{2}\left[\left(\frac{\alpha-2w}{2+\beta}+\frac{\beta d_M}{4-\beta^2}\right)^2+\right.\right. \\
&\left.\left.2\beta\left(\frac{\alpha-2w}{2+\beta}+\frac{\beta d_M}{4-\beta^2}\right)\left(\frac{\alpha-2w}{2+\beta}-\frac{2d_M}{4-\beta^2}\right)+\left(\frac{\alpha-2w}{2+\beta}-\frac{2d_M}{4-\beta^2}\right)^2\right]\right\}+ \\
&\Big\{1-\big[1-\lambda_I(e_{cc})\big]\big[1-\lambda_I(e_{c1})\lambda_I(e_{c2})\big]\Big\} \\
&\left[2(\alpha-d_M)\frac{\alpha-2w-d_M}{2+\beta}-(\beta+1)\left(\frac{\alpha-2w-d_M}{2+\beta}\right)^2\right]- \\
&\big[\lambda_I(e_{c1})+\lambda_I(e_{cc})+\lambda_I(e_{c2})\big]d_S-(1-e)(e_{c1}+e_{cc}+e_{c2})\hat{d}_S- \\
&\left[K\mathbb{1}_{e_{c1}>0}+\frac{a}{2}(e_{c1})^2\right]-\left[K\mathbb{1}_{e_{cc}>0}+\frac{a}{2}(e_{cc})^2\right]-\left[K\mathbb{1}_{e_{c2}>0}+\frac{a}{2}(e_{c2})^2\right]-\frac{3}{2}be^2. \qquad \text{(B.2)}
\end{aligned}
$$

### B.4 Sufficient Conditions for the Joint-Concavity of the Coalition's Profit Function

To ensure that the coalition's profit function $\Pi^b(e_{c1}, 2\bar{e}-e_{c1}-e_{c2}, e_{c2})$ is jointly concave in the auditing efforts $(e_{c1}, e_{c2})$, we require the associated Hessian matrix to be negative semidefinite, which is guaranteed if

$$\frac{\partial^2\Pi^b(e_{c1}, 2\bar{e}-e_{c1}-e_{c2}, e_{c2})}{\partial e_{c1}^2} \le 0 \text{ and}$$

$$
\begin{aligned}
\Theta \triangleq &\frac{\partial^2\Pi^b(e_{c1}, 2\bar{e}-e_{c1}-e_{c2}, e_{c2})}{\partial e_{c1}^2}\frac{\partial^2\Pi^b(e_{c1}, 2\bar{e}-e_{c1}-e_{c2}, e_{c2})}{\partial e_{c2}^2}- \\
&\left(\frac{\partial^2\Pi^b(e_{c1}, 2\bar{e}-e_{c1}-e_{c2}, e_{c2})}{\partial e_{c1}\partial e_{c2}}\right)^2 \ge 0.
\end{aligned}
$$

Observe that

$$\frac{\partial^3 \Pi^b(e_{c1}, 2\bar{e} - e_{c1} - e_{c2}, e_{c2})}{\partial e_{c1}^2 \partial \alpha} = -\frac{4d_M(2-\beta)^2\big[r(1-e)\big]^2}{(4-\beta^2)^2} < 0;$$

$$\begin{aligned}\frac{\partial \Theta}{\partial \alpha} =& \frac{8d_M\big[r(1-e)\big]^2}{(2-\beta)^2(2+\beta)^4}\Big\{(4-\beta^2)^2 a - 8\beta\big[r(1-e)\big]^2\Big\{d_M\big[1 - r(1-e)(1-2\bar{e}+e_{c1}+e_{c2})\big] \\ & \big[d_M + 2(\hat{w}-w)\big] + (\hat{w}-w)^2\Big\}\Big\} > 0,\end{aligned}$$

when $a > a_c \triangleq \frac{8\beta\left[r(1-e)\right]^2\left\{d_M\left[1-r(1-e)(1-2\bar{e})\right]\left[d_M+2(\hat{w}-w)\right]+(\hat{w}-w)^2\right\}}{(4-\beta^2)^2}$.

Consequently, there exist thresholds $\alpha_c^1$ and $a_c$ such that, if the MWTP parameter $\alpha > \alpha_c^1$ and the auditing variable-cost parameter $a > a_c$, the coalition's profit function is jointly concave in $(e_{c1}, e_{c2})$. □

### B.5 Proofs of Technical Results in Sections 2.4, 2.5, and 2.6

**Proof of Lemma 2.4.1:** For each of the five cases listed in the statement of the lemma, we only provide the profit functions of the two buyers. The equilibrium sourcing quantities and profits can then be obtained in straightforward manner, and are provided in the statement of the lemma.

- If no buyer experiences the MWTP damage of $d_M$, then the buyers' profit functions are $\pi_1 = (\alpha - q_1 - \beta q_2 - 2w)q_1$ and $\pi_2 = (\alpha - q_2 - \beta q_1 - 2w)q_2$.

- If one supplier causes damage to buyer $B_2$ and buyer $B_1$ does not suffer any damage, then the buyers' profit functions are $\pi_1 = (\alpha - q_1 - \beta q_2 - 2w)q_1$ and $\pi_2 = (\alpha - d_M - q_2 - \beta q_1 - w - \hat{w})q_2$.

- If one supplier causes damage to buyer $B_1$ and one supplier causes damage to buyer $B_2$, then the buyers' profit functions are $\pi_1 = (\alpha - d_M - q_1 - \beta q_2 - w - \hat{w})q_1$ and $\pi_2 = (\alpha - d_M - q_2 - \beta q_1 - w - \hat{w})q_2$.

- If one supplier causes damage to buyer $B_1$ and two suppliers cause damage to buyer $B_2$, then the buyers' profit functions are $\pi_1 = (\alpha - d_M - q_1 - \beta q_2 - w - \hat{w})q_1$ and $\pi_2 = (\alpha - d_M - q_2 - \beta q_1 - 2\hat{w})q_2$.

- If two suppliers cause damage to each buyer, then the buyers' profit functions are $\pi_1 = (\alpha - d_M - q_1 - \beta q_2 - 2\hat{w})q_1$ and $\pi_2 = (\alpha - d_M - q_2 - \beta q_1 - 2\hat{w})q_2$. □

Before we prove Proposition 2.4.1, we establish several intermediate results (Lemmas B.5.1 through B.5.4 below).

**Lemma B.5.1.** *When the buyers do not compete, one supplier auditing his independent supplier and the other buyer auditing none of his suppliers cannot be sustained in equilibrium.*

**Proof of Lemma B.5.1:** We establish the result by defining a threshold $K_u$ such that if $B_1$ audits $S_1$ and $B_2$ does not audit any supplier, then (1) if the auditing fixed cost $K \geq K_u$, then $B_1$ is better-off not auditing any supplier; (2) if $K < K_u$, then $B_2$ has an incentive to deviate to audit his independent supplier $S_2$.

(1) If $B_1$ audits $S_1$, then regardless of whether $B_2$ audits $S_2$ or does not audit any supplier, we note that $B_2$'s effort does not affect $B_1$'s profit. Buyer $B_1$ decides his auditing effort $e_{11}$ to maximize his expected profit:

$$\begin{aligned}\Pi_1^b(e_{11}, 0) = &\big[1 - r(1-e)\big]\big[1 - r(1-e)(1-e_{11})\big]\left(\frac{\alpha - 2w}{2}\right)^2 + \\ &\Big\{r(1-e)(1-e_{11})\big[1 - r(1-e)\big] + \big[1 - r(1-e)(1-e_{11})\big]r(1-e)\Big\} \\ &\left(\frac{\alpha - w - \hat{w} - d_M}{2}\right)^2 + \\ &\big[r(1-e)\big]^2(1-e_{11})\left(\frac{\alpha - 2\hat{w} - d_M}{2}\right)^2 - \Big[K\mathbb{1}_{e_{11}>0} + \frac{a}{2}(e_{11})^2\Big]. \end{aligned} \tag{B.3}$$

Let us first assume $K = 0$. The optimal auditing effort is:

$$e_{11}^* = \frac{1}{4a} r(1-e) \left\{ \begin{array}{l} \big[1 - r(1-e)\big](\alpha - 2w)^2 - \big[1 - 2r(1-e)\big](\alpha - w - \hat{w} - d_M)^2 - \\ r(1-e)(\alpha - 2\hat{w} - d_M)^2 \end{array} \right\}. \tag{B.4}$$

Let

$$K_u \triangleq \Pi_1^b(e_{11}^*, 0)\big|_{K=0} - \Pi_1^b(0, 0), \tag{B.5}$$

where $\Pi_1^b(e_{11}^*, 0)\big|_{K=0}$ represents $B_1$'s profit with auditing effort $e_{11}^*$ excluding the fixed cost (or alternatively setting $K = 0$). Therefore, if the auditing fixed cost $K > K_u$, $B_1$ has an incentive to deviate from auditing $S_1$ to not auditing any supplier. If $K = K_u$, $B_1$ is indifferent between auditing $S_1$ and no-audit, and chooses no-audit by assumption.

(2) From (B.3) and the fact that $B_2$'s profit function is symmetric to that of $B_1$, we know that if $e_{11} = e_{22} = \hat{e}$, then $\Pi_1^b(\hat{e}, 0) = \Pi_2^b(\hat{e}, 0)$. From the definition of $K_u$ above, we know that if $K < K_u$, then it is profitable for $B_1$ to audit his independent supplier $S_1$ instead of not auditing any supplier, i.e., $\max_{e_{11}} \Pi_1^b(e_{11}, 0) > \Pi_1^b(0, 0)$. Thus, by symmetry, it is also more profitable for $B_2$ to audit his independent supplier $S_2$ instead of not auditing any supplier; hence, $B_2$ has an incentive to deviate from no-audit to auditing $S_2$. □

**Lemma B.5.2.** *When the buyers do not compete, one buyer auditing the common supplier while the other auditing none of his suppliers cannot be sustained in equilibrium.*

**Proof of Lemma B.5.2:** We establish the result by showing that in the case where $B_1$ audits none of his suppliers and $B_2$ audits $S_c$, (1) if the auditing fixed cost $K \geq K_u$, where $K_u$ is as defined in (B.5), $B_2$ is better off not auditing any of his suppliers; (2) there exists a threshold $K_1 \geq K_u$, such that if $K < K_1$, $B_1$ has an incentive to deviate to auditing $S_1$.

(1) When $B_2$ audits $S_c$ then regardless of whether $B_1$ audits $S_1$ or does not audit any supplier, note that $B_1$'s effort does not affect $B_2$'s profit; $B_2$ decides his auditing effort $e_{2c}$ to maximize

his expected profit:

$$\Pi_2^b(0,e_{2c}) = \big[1-r(1-e)\big]\big[1-r(1-e)(1-e_{2c})\big]\left(\frac{\alpha-2w}{2}\right)^2 + \\ \Big\{r(1-e)(1-e_{2c})\big[1-r(1-e)\big] + \big[1-r(1-e)(1-e_{2c})\big]r(1-e)\Big\} \\ \left(\frac{\alpha-w-\hat{w}-d_M}{2}\right)^2 + \\ \big[r(1-e)\big]^2(1-e_{2c})\left(\frac{\alpha-2\hat{w}-d_M}{2}\right)^2 - \left[K\mathbb{1}_{e_{2c}>0} + \frac{a}{2}(e_{2c})^2\right]. \tag{B.6}$$

Let us first assume $K=0$. Let $e_{2c}^*$ denote $B_2$'s optimal auditing effort. From (B.3) and (B.6), observe that if $e_{11}=e_{2c}=e$, then $\Pi_1^b(e,0)=\Pi_2^b(0,e)$. This implies that

$$\Pi_1^b(e_{11}^*,0) = \max_{e_{11}} \Pi_1^b(e_{11},0) = \max_{e_{2c}} \Pi_2^b(0,e_{2c}) = \Pi_2^b(0,e_{2c}^*).$$

It follows that

$$\Pi_2^b(0,e_{2c}^*)\big|_{K=0} - \Pi_2^b(0,0) = \Pi_1^b(e_{11}^*,0)\big|_{K=0} - \Pi_1^b(0,0) = K_u.$$

If the auditing fixed cost $K>K_u$, then $B_2$ has an incentive to deviate from auditing $S_c$ to not auditing any supplier. If $K=K_u$, $B_2$ is indifferent between auditing $S_c$ and no-audit, and chooses no-audit by assumption.

(2) Let us first assume $K=0$. Let $\hat{e}_{11}$ denote $B_1$'s best-response auditing effort if he deviates to auditing $S_1$, i.e., $\Pi_1^b(\hat{e}_{11},0;0,e_{2c}^*) = \max_{e_{11}} \Pi_1^b(e_{11},0;0,e_{2c}^*)$. Let

$$K_1 \triangleq \Pi_1^b(\hat{e}_{11},0;0,e_{2c}^*)\big|_{K=0} - \Pi_1^b(0,0;0,e_{2c}^*).$$

If the auditing fixed cost $K<K_1$, then $B_1$ has an incentive to deviate to auditing $S_1$. Finally, we note that

$$K_1 = \Pi_1^b(\hat{e}_{11},0;0,e_{2c}^*)\big|_{K=0} - \Pi_1^b(0,0;0,e_{2c}^*) = \max_{e_{11}} \Pi_1^b(e_{11},0;0,e_{2c}^*)\Big|_{K=0} - \Pi_1^b(0,0;0,e_{2c}^*) \\ \geq \Pi_1^b(e_{11}^*,0;0,e_{2c}^*)\big|_{K=0} - \Pi_1^b(0,0;0,e_{2c}^*) \geq \Pi_1^b(e_{11}^*,0;0,0)\big|_{K=0} - \Pi_1^b(0,0;0,0) \\ = \Pi_1^b(e_{11}^*,0)\big|_{K=0} - \Pi_1^b(0,0) = K_u. \tag{B.7}$$

The second inequality above follows since

$$\frac{\partial\big[\ \Pi_1^b(e_{11},0;0,e_{2c})\big|_{K=0} - \Pi_1^b(0,0;0,e_{2c})\big]}{\partial e_{2c}}$$

$$=\frac{1}{4}e_{11}[r(1-e)]^2\big[d_M(2\alpha-d_M-2w)+2(\hat{w}-w)^2\big]\geq 0. \qquad \square$$

**Lemma B.5.3.** *When the buyers do not compete, both buyers auditing the common supplier cannot be sustained in equilibrium.*

**Proof of Lemma B.5.3:** We establish the result by showing that when $B_2$ audits $S_c$, $B_1$ has an incentive to deviate from auditing $S_c$. The expected profit function of $B_1$ when both the buyers audit $S_c$ is:

$$\begin{aligned}
&\Pi_1^b(0,e_{1c};0,e_{2c})\\
=&\left[1-r(1-e)\prod_{i=1}^{2}(1-e_{ic})\right]\big[1-r(1-e)\big]\left(\frac{\alpha-2w}{2}\right)^2+\\
&\left\{r(1-e)\left[1-r(1-e)\prod_{i=1}^{2}(1-e_{ic})\right]+r(1-e)\prod_{i=1}^{2}(1-e_{ic})\big[1-r(1-e)\big]\right\}\\
&\left(\frac{\alpha-w-\hat{w}-d_M}{2}\right)^2+\\
&\big[r(1-e)\big]^2\prod_{i=1}^{2}(1-e_{ic})\left(\frac{\alpha-2\hat{w}-d_M}{2}\right)^2-\left[K\mathbb{1}_{e_{1c}>0}+\frac{a}{2}(e_{1c})^2\right].
\end{aligned}$$

Using the symmetry of the profit functions and the resulting symmetric best-response functions, it can be shown that the best-response auditing efforts of both the buyers are the same; let $e_s = \arg\max_{e_{ic}} \Pi_i^b(0,e_{ic};0,e_s)$. Then, we have

$$\Pi_1^b(e_s,0;0,e_s)-\Pi_1^b(0,e_s;0,e_s)=r(1-e){e_s}^2\left[\left(\frac{\alpha-2w}{2}\right)^2-\left(\frac{\alpha-w-\hat{w}-d_M}{2}\right)^2\right]>0,$$

implying that $B_1$ has an incentive to deviate from auditing $S_c$. $\square$

**Lemma B.5.4.** *When the buyers do not compete and $K < K_u$, (1) each buyer auditing his independent supplier is an equilibrium, (2) one buyer auditing his independent supplier and the other auditing the common supplier is also an equilibrium, and (3) the equilibrium in (2) is Pareto-dominant.*

**Proof of Lemma B.5.4:** (1) When $B_1$ audits $S_1$ and $B_2$ audits $S_2$, $B_1$ decides his auditing effort $e_{11}$ to maximize his expected profit (specified in (B.3)); the optimal effort $e_{11}^*$ is specified in (B.4).

If $B_1$ were to deviate and, instead, audit $S_c$, then his auditing effort $e_{1c}$ maximizes his expected profit:

$$\begin{aligned}\Pi_1^b(0, e_{1c}) =& \big[1 - r(1-e)\big]\big[1 - r(1-e)(1-e_{1c})\big]\left(\frac{\alpha - 2w}{2}\right)^2 + \\ & \Big\{r(1-e)(1-e_{1c})\big[1 - r(1-e)\big] + \big[1 - r(1-e)(1-e_{1c})\big]r(1-e)\Big\} \\ & \left(\frac{\alpha - w - \hat{w} - d_M}{2}\right)^2 + \\ & \big[r(1-e)\big]^2(1-e_{1c})\left(\frac{\alpha - 2\hat{w} - d_M}{2}\right)^2 - \big[K\mathbb{1}_{e_{1c}>0} + \frac{a}{2}(e_{1c})^2\big].\end{aligned}$$

Observe that if $e_{11} = e_{1c} = \hat{e}$, $\Pi_1^b(\hat{e}, 0) = \Pi_1^b(0, \hat{e})$, which implies that

$$\Pi_1^b(e_{11}^*, 0) = \max_{e_{1c}} \Pi_1^b(0, e_{1c}). \tag{B.8}$$

Thus, $B_1$ has no incentive to deviate to auditing $S_c$. Further, when $K < K_u$, it follows immediately from (B.5) that $B_1$ has no incentive to deviate from auditing $S_1$ to not auditing any of his suppliers. The same arguments hold for $B_2$ by symmetry.

(2) We establish the result by showing that (a) when $B_2$ audits $S_2$, $B_1$ has no incentive to deviate from auditing $S_c$ to auditing $S_1$ or to not auditing any supplier; (b) when $B_1$ audits $S_c$, $B_2$ has no incentive to deviate from auditing $S_2$ to auditing $S_c$ or to not auditing any supplier.

(a) The claim that $B_1$ has no incentive to deviate to auditing $S_1$ follows from (B.8). The claim that $B_1$ has no incentive to deviate to not auditing any supplier follows from (B.5), (B.8), and $K < K_u$.

(b) When $B_1$ audits $S_c$ and $B_2$ audits $S_2$, $B_1$'s optimal auditing effort is $e_{1c}^* = e_{11}^*$, where $e_{11}^*$ is defined in (B.4), since $\Pi_1^b(\hat{e}, 0) = \Pi_1^b(0, \hat{e})$ for any $\hat{e}$. Buyer $B_2$ decides $e_{22}$ to maximize his expected profit:

$$
\begin{aligned}
&\Pi_2^b(e_{22},0;0,e_{1c}^*)\\
=&\big[1-r(1-e)(1-e_{22})\big]\big[1-r(1-e)(1-e_{1c}^*)\big]\left(\frac{\alpha-2w}{2}\right)^2+\\
&\Big\{r(1-e)(1-e_{22})\big[1-r(1-e)(1-e_{1c}^*)\big]+\big[1-r(1-e)(1-e_{22})\big]r(1-e)(1-e_{1c}^*)\Big\}\\
&\left(\frac{\alpha-w-\hat{w}-d_M}{2}\right)^2+\\
&\big[r(1-e)\big]^2(1-e_{22})(1-e_{1c}^*)\left(\frac{\alpha-2\hat{w}-d_M}{2}\right)^2-\Big[K+\frac{a}{2}(e_{22})^2\Big].
\end{aligned}
$$

It is straightforward to verify that $B_2$'s optimal auditing effort is:

$$
\begin{aligned}
\hat{e}_{22}=&\frac{1}{4a}r(1-e)\left\{\begin{array}{l}\big[1-r(1-e)\big](\alpha-2w)^2-\big[1-2r(1-e)\big](\alpha-w-\hat{w}-d_M)^2-\\ r(1-e)(\alpha-2\hat{w}-d_M)^2\end{array}\right\}+\\
&\frac{1}{16a^2}\big[r(1-e)\big]^3\left\{\begin{array}{l}\big[2(\alpha-2w)-d_M\big]d_M+\\ 2(\hat{w}-w)\end{array}\right\}\left\{\begin{array}{l}\big[1-r(1-e)\big](\alpha-2w)^2-\\ r(1-e)(\alpha-2\hat{w}-d_M)^2-\\ \big[1-2r(1-e)\big](\alpha-w-\hat{w}-\\ d_M)^2\end{array}\right\}.
\end{aligned}
$$

If $B_2$ were to audit $S_c$, then let $\hat{e}_{2c}=\arg\max_{e_{2c}}\Pi_2^b(0,e_{2c};0,e_{1c}^*)$. Then, we have

$$\Pi_2^b(\hat{e}_{22},0;0,e_{1c}^*)\geq\Pi_2^b(\hat{e}_{2c},0;0,e_{1c}^*)>\Pi_2^b(0,\hat{e}_{2c};0,e_{1c}^*).$$

The first inequality follows since $\Pi_2^b(\hat{e}_{22},0;0,e_{1c}^*)=\max_{e_{22}}\Pi_2^b(e_{22},0;0,e_{1c}^*)\geq\Pi_2^b(\hat{e}_{2c},0;0,e_{1c}^*)$. The second inequality follows since

$$\Pi_2^b(\hat{e}_{2c},0;0,e_{1c}^*)-\Pi_2^b(0,\hat{e}_{2c};0,e_{1c}^*)=r(1-e)e_{1c}^*\hat{e}_{2c}\left[\left(\frac{\alpha-2w}{2}\right)^2-\left(\frac{\alpha-w-\hat{w}-d_M}{2}\right)^2\right]>0.$$

Thus, $B_2$ has no incentive to deviate from auditing $S_2$ to auditing $S_c$.

Recall from (B.7) that $K_1=\Pi_2^b(\hat{e}_{22},0;0,e_{1c}^*)\big|_{K=0}-\Pi_2^b(0,0;0,e_{1c}^*)\geq K_u$. Therefore, when the fixed cost $K<K_u$, $B_2$ does not have an incentive to deviate from auditing $S_2$ to not auditing any supplier.

(3) We show the Pareto dominance of the equilibrium in (2) above by comparing the profits of each buyer in the following two cases:

**(Case A)** $B_1$ audits $S_1$ and $B_2$ audits $S_c$ in equilibrium; in this case, we let $e_{1A}$ and $e_{2A}$ denote the equilibrium auditing efforts of $B_1$ and $B_2$, respectively, and

**(Case B)** $B_1$ audits $S_1$ and $B_2$ audits $S_2$ in equilibrium; in this case, we let $e_{1B}$ and $e_{2B}$ denote the equilibrium auditing efforts of $B_1$ and $B_2$, respectively.

First, from the proof of (1) above, we have that $e_{2A} = e_{2B}$, and therefore $B_2$ earns the same profit under both cases, i.e., $\Pi_2^b(0, e_{2A}) = \Pi_2^b(e_{2B}, 0)$. Second, by the Envelope Theorem, $B_1$'s expected profit at his best-response auditing effort $e_{11}^*(e_{2c})$ increases in $B_2$'s auditing effort $e_{2c}$; that is,

$$\begin{aligned}&\frac{\partial \Pi_1^b(e_{11}^*(e_{2c}), 0; 0, e_{2c})}{\partial e_{2c}}\\
=&r(1-e)\big[1 - r(1-e)(1-e_{11}^*(e_{2c}))\big]\left[\left(\frac{\alpha - 2w}{2}\right)^2 - \left(\frac{\alpha - w - \hat{w} - d_M}{2}\right)^2\right] +\\
&\big[r(1-e)\big]^2(1-e_{11}^*(e_{2c}))\left[\left(\frac{\alpha - w - \hat{w} - d_M}{2}\right)^2 - \left(\frac{\alpha - 2\hat{w} - d_M}{2}\right)^2\right] > 0,\end{aligned}$$

where $\Pi_1^b(e_{11}^*(e_{2c}), 0; 0, e_{2c}) = \max_{e_{11}} \Pi_1^b(e_{11}, 0; 0, e_{2c})$. Note that we have $e_{2A} = e_{2c}^* > 0$ in case A and $e_{2c} = 0$ in case B. Thus, it is immediate that $\Pi_1^b(e_{1A}, 0; 0, e_{2A}) \geq \Pi_1^b(e_{1B}, 0; 0, 0) = \Pi_1^b(e_{1B}, 0; e_{2B}, 0)$. The last equality follows since $\Pi_1^b(e_{11}, 0; e_{22}, 0)$ does not change with $e_{22}$. Since $B_2$'s profits are the same under both cases and $B_1$ obtains a higher profit in case A, it follows that the equilibrium in (2) is Pareto-dominant. □

**Proof of Proposition 2.4.1:** When $K < K_u$, the result follows from Lemmas B.5.1, B.5.2, B.5.3 and B.5.4. When $K \geq K_u$, the result follows from arguments similar to those in the proofs of Lemmas B.5.1, B.5.2 and B.5.3. □

We now establish four intermediate results: Lemmas B.5.5, B.5.6, B.5.7, and B.5.8; these results will be used in the proof of Proposition 2.4.2.

**Lemma B.5.5.** *When the buyers compete, there exists a threshold $K_u^M$ such that, if the auditing fixed cost $K < K_u^M$, then each buyer auditing his independent supplier is an equilibrium; each buyer exerts an auditing effort of $e_I^*$, which we defined in* (2.1)*. If $K \geq K_u^M$, then each buyer auditing his independent supplier cannot be sustained in equilibrium.*

**Proof of Lemma B.5.5:** To establish the claimed result, we show that there exists a threshold $K_u^M$ such that, when $B_1$ audits $S_1$ and $B_2$ audits $S_2$: (a) if the auditing fixed cost $K < K_u^M$, then $B_1$ has no incentive to deviate to not auditing any supplier and if $K \geq K_u^M$, $B_1$ is better off not auditing any supplier. (b) for any $K$, $B_1$ has no incentive to deviate to auditing $S_c$.

(a) Let us first assume $K = 0$. When $B_1$ audits $S_1$ and $B_2$ audits $S_2$, $B_1$'s best-response function $e_{11}^*(e_{22})$ is:

$$\begin{aligned}
e_{11}^*(e_{22}) =& \frac{r(1-e)\big[1-r(1-e)\big]\big[1-r(1-e)(1-e_{22})\big]}{a} \\
& \left[\left(\frac{\alpha-2w}{2+\beta}\right)^2 - \left(\frac{\alpha}{2+\beta} - \frac{2d_M+2(1-\beta)w+2\hat{w}}{4-\beta^2}\right)^2\right] + \\
& \frac{r(1-e)\big[1-r(1-e)\big]r(1-e)(1-e_{22})}{a} \\
& \left[\left(\frac{\alpha}{2+\beta} + \frac{\beta d_M-(4-\beta)w+\beta\hat{w}}{4-\beta^2}\right)^2 - \left(\frac{\alpha-d_M-w-\hat{w}}{2+\beta}\right)^2\right] + \\
& \frac{\big[r(1-e)\big]^2\big[1-r(1-e)(1-e_{22})\big]}{a} \\
& \left[\left(\frac{\alpha-d_M-w-\hat{w}}{2+\beta}\right)^2 - \left(\frac{\alpha-d_M}{2+\beta} - \frac{(4-\beta)\hat{w}-\beta w}{4-\beta^2}\right)^2\right] + \\
& \frac{\big[r(1-e)\big]^2 r(1-e)(1-e_{22})}{a} \\
& \left[\left(\frac{\alpha-d_M}{2+\beta} - \frac{2w+2(1-\beta)\hat{w}}{4-\beta^2}\right)^2 - \left(\frac{\alpha-d_M-2\hat{w}}{2+\beta}\right)^2\right].
\end{aligned} \tag{B.9}$$

Buyer $B_2$'s best-response function is symmetric to that of $B_1$. By solving the system of best-response functions, the equilibrium efforts are: $e_{11}^* = e_{22}^* = e_I^*$, where $e_I^*$ is as defined in

(2.1). Let

$$K_u^M \triangleq \Pi_1^b(e_I^*, 0; e_I^*, 0)\big|_{K=0} - \Pi_1^b(0, 0; e_I^*, 0). \tag{B.10}$$

If $K < K_u^M$, when $B_2$ audits $S_2$ with the effort of $e_I^*$ and $B_1$ audits $S_1$ with the effort of $e_I^*$, $B_1$ has no incentive to deviate to not auditing any supplier. If $K > K_u^M$, $B_1$ has an incentive to deviate from auditing $S_1$ to not auditing any supplier. If $K = K_u^M$, $B_1$ is indifferent between auditing $S_1$ and not auditing any supplier, and chooses the latter by our assumption.

(b) Let $\hat{e}_{1c}$ denote $B_1$'s best-response auditing effort if he deviates to auditing $S_c$, i.e., $\Pi_1^b(0, \hat{e}_{1c}; e_I^*, 0) = \max_{e_{1c}} \Pi_1^b(0, e_{1c}; e_I^*, 0)$. Then, observe that $\Pi_1^b(e_I^*, 0; e_I^*, 0) \geq \Pi_1^b(\hat{e}_{1c}, 0; e_I^*, 0)$ $> \Pi_1^b(0, \hat{e}_{1c}; e_I^*, 0)$. The first inequality follows since $\Pi_1^b(e_I^*, 0; e_I^*, 0) = \max_{e_{11}} \Pi_1^b(e_{11}, 0; e_I^*, 0)$ and the second inequality follows from the fact that, for any auditing efforts $e_1 > 0$ and $e_2$, we have

$$\begin{aligned}
&\Pi_1^b(e_1, 0; e_2, 0) - \Pi_1^b(0, e_1; e_2, 0)\\
=&\big[1 - r(1-e)(1-e_2)\big] r(1-e)e_1\\
&\left[\left(\frac{\alpha - d_M - w - \hat{w}}{2+\beta}\right)^2 - \left(\frac{\alpha}{2+\beta} - \frac{2d_M + 2(1-\beta)w + 2\hat{w}}{4-\beta^2}\right)^2\right] +\\
&\big[r(1-e)\big]^2(1-e_2)e_1 \left[\left(\frac{\alpha - d_M}{2+\beta} - \frac{2w + 2(1-\beta)\hat{w}}{4-\beta^2}\right)^2 - \left(\frac{\alpha - d_M - w - \hat{w}}{2+\beta}\right)^2\right]\\
=&\frac{\big[1 - r(1-e)(1-e_2)\big] r(1-e)e_1\beta(d_M + \hat{w} - w)}{(4-\beta^2)^2}\\
&\Big\{2\big[(2-\beta)\alpha - 2d_M - 2(1-\beta)w - 2\hat{w}\big] + \beta(\hat{w} - w) + \beta d_M\Big\} +\\
&\frac{\big[r(1-e)\big]^2(1-e_2)e_1\beta(d_M + \hat{w} - w)}{(4-\beta^2)^2}\\
&\Big\{2\big[(2-\beta)\alpha - 2d_M - 2(1-\beta)w - 2\hat{w}\big] + 3\beta(\hat{w} - w) + 2\beta d_M\Big\} > 0.
\end{aligned} \tag{B.11}$$

The last inequality holds since $(2-\beta)\alpha - 2d_M > 2(1-\beta)w + 2\hat{w}$ (the condition in Section 2.3 which ensures that the buyers order positive amounts). It follows that $B_1$ has no incentive to deviate to audit $S_c$. □

**Lemma B.5.6.** *When the buyers compete, there exist thresholds $K_u^L$ and $K_u^H$ such that, if the auditing fixed cost $K_u^L \leq K < K_u^H$, then one buyer auditing his independent supplier (with an auditing effort of $\hat{e}_I$, which we defined in* (2.2) *earlier) and the other buyer not auditing any supplier, is an equilibrium. Otherwise, the possibility of one buyer auditing his independent supplier and the other not auditing any supplier cannot be sustained in equilibrium.*

**Proof of Lemma B.5.6:** We establish the result in two steps.

• We first show that there exists a threshold $K_u^L$, such that if $B_1$ does not audit any supplier and $B_2$ audits $S_2$ then (a) if $K \geq K_u^L$, then $B_1$ has no incentive to deviate to auditing $S_1$ or $S_c$, and (b) if $K < K_u^L$, then $B_1$ has an incentive to deviate to auditing $S_1$.

Let us first assume $K = 0$. If $B_1$ does not audit any supplier and $B_2$ audits $S_2$, then $B_2$'s best-response auditing effort is $e_{22}^*(0) = \hat{e}_I$, where $\hat{e}_I$ is defined in (2.2). If $B_1$ deviates to auditing $S_1$, $B_1$'s best-response auditing effort is $e_{11}^*(\hat{e}_I)$, which is defined in (B.9). Let

$$K_u^L \triangleq \Pi_1^b(e_{11}^*(\hat{e}_I), 0; \hat{e}_I, 0)\big|_{K=0} - \Pi_1^b(0, 0; \hat{e}_I, 0). \tag{B.12}$$

If $K \geq K_u^L$, $B_1$ has no incentive to deviate to auditing $S_1$; otherwise, he does.

If $B_1$ deviates to audit $S_c$ with an auditing effort of, say, $e_{1c} > 0$, then he can earn a higher profit by, instead, auditing $S_1$ with the same effort, i.e., $\Pi_1^b(e_{1c}, 0; \hat{e}_I, 0) > \Pi_1^b(0, e_{1c}; \hat{e}_I, 0)$, which follows from (B.11). Therefore, if $K < K_u^L$, then $B_1$ has no incentive to deviate to auditing $S_c$ either.

• We next show that there exists a threshold $K_u^H$ such that if $B_1$ does not audit any supplier and $B_2$ audits $S_2$, then (a) if $K < K_u^H$, then $B_2$ has no incentive to deviate to auditing $S_c$ or to not auditing any supplier, and (b) if $K \geq K_u^H$, then $B_2$ is better off not auditing any supplier.

Let us first assume $K = 0$. Recall that if $B_1$ audits none of his suppliers and $B_2$ audits $S_2$, then $B_2$'s best-response auditing effort is $\hat{e}_I$, which is defined in (2.2). Let

$$K_u^H \triangleq \Pi_2^b(\hat{e}_I, 0; 0, 0)\big|_{K=0} - \Pi_2^b(0, 0; 0, 0). \tag{B.13}$$

If $K < K_u^H$, then $B_2$ has no incentive to deviate to not auditing any supplier; otherwise, $B_2$ is better off not auditing any supplier. Also, if $B_2$ deviates to audit $S_c$ with an effort of, say, $e_{2c} > 0$, then he can earn a higher profit by, instead, auditing $S_2$ with the same effort. This is because for any $e_{2c} > 0$, since the profit function of $B_2$ is symmetric to that of $B_1$, we have $\Pi_2^b(e_{2c}, 0; 0, 0) - \Pi_2^b(0, e_{2c}; 0, 0) = \Pi_1^b(e_{2c}, 0; 0, 0) - \Pi_1^b(0, e_{2c}; 0, 0) > 0$ by (B.11). Thus, $B_2$ will not deviate to audit $S_c$. □

**Lemma B.5.7.** *The thresholds $K_u^M$ (defined in Lemma B.5.5), and $K_u^L$ and $K_u^H$ (defined in Lemma B.5.6) satisfy $K_u^L < K_u^M < K_u^H$.*

**Proof of Lemma B.5.7:** We first make two observations. First, if $B_2$ audits $S_2$, then the difference in $B_1$'s profit between auditing $S_1$ and not auditing any supplier decreases in $B_2$'s auditing effort $e_{22}$. This follows, since for given any $e_{11} > 0$ and $e_{22}$, we have

$$\begin{aligned}&\frac{\partial\, \Pi_1^b(e_{11}, 0; e_{22}, 0)\big|_{K=0} - \Pi_1^b(0, 0; e_{22}, 0)}{\partial e_{22}} \\ &= -e_{11}\big[r(1-e)\big]^2\big[1 - r(1-e)\big]\frac{4\beta(d_M + \hat{w} - w)^2}{(4-\beta^2)^2} - e_{11}\big[r(1-e)\big]^3\frac{4\beta(\hat{w} - w)^2}{(4-\beta^2)^2} < 0.\end{aligned} \tag{B.14}$$

Second, if $B_1$ audits $S_1$ and $B_2$ audits $S_2$, then $B_1$'s best-response effort $e_{11}^*(e_{22})$, defined in (B.9), decreases in $e_{22}$. This follows because

$$\begin{aligned}&\frac{\partial e_{11}^*(e_{22})}{\partial e_{22}} \\ &= -\frac{4\beta\big[r(1-e)\big]^2\Big\{d_M^2\big[1 - r(1-e)\big] + 2d_M\big[1 - r(1-e)\big](\hat{w} - w) + (\hat{w} - w)^2\Big\}}{(4-\beta^2)^2} < 0.\end{aligned}$$

Therefore, noticing that $\hat{e}_I = e_{11}^*(0)$ and $e_I^* = e_{11}^*(e_I^*)$, we have

$$\hat{e}_I > e_I^*. \tag{B.15}$$

We now establish the claimed result. Recall the definitions of the thresholds from (B.10), (B.12), and (B.13):

$$\begin{aligned} K_u^L &= \Pi_1^b(e_{11}^*(\hat{e}_I), 0; \hat{e}_I, 0)\big|_{K=0} - \Pi_1^b(0, 0; \hat{e}_I, 0), \\ K_u^M &= \Pi_1^b(e_I^*, 0; e_I^*, 0)\big|_{K=0} - \Pi_1^b(0, 0; e_I^*, 0), \\ K_u^H &= \Pi_2^b(\hat{e}_I, 0; 0, 0)\big|_{K=0} - \Pi_2^b(0, 0; 0, 0). \end{aligned}$$

We have

$$\begin{aligned} K_u^L &< \Pi_1^b(e_{11}^*(\hat{e}_I), 0; e_I^*, 0)\big|_{K=0} - \Pi_1^b(0, 0; e_I^*, 0) \le K_u^M \\ &< \Pi_1^b(e_I^*, 0; 0, 0)\big|_{K=0} - \Pi_1^b(0, 0; 0, 0) = \Pi_2^b(e_I^*, 0; 0, 0)\big|_{K=0} - \Pi_2^b(0, 0; 0, 0) \le K_u^H. \end{aligned}$$

The first inequality follows from (B.14) and (B.15). The second inequality follows from the definition of $e_I^*$. The third inequality follows from (B.14). The equality holds since the buyers' profit functions are symmetric. The last inequality follows from the definition of $\hat{e}_I$.

□

The proof of the following result is similar to those of Lemmas B.5.5 and B.5.6, and omitted for brevity.

**Lemma B.5.8.** *When the buyers compete, the following possibilities cannot be sustained in equilibrium: (a) one buyer audits his independent supplier and the other buyer audits the common supplier, (b) both buyers audit the common supplier, and (c) one buyer audits the common supplier and the other buyer does not audit any supplier.*

**Proof of Proposition 2.4.2:** If the auditing fixed cost $K < K_u^H$, then the claimed result follows by combining the conclusions of Lemmas B.5.5, B.5.6, B.5.7, and B.5.8. If $K \ge K_u^H$, then it is straightforward to show that neither buyer should audit any supplier using an argument similar to that in the proof of Lemma B.5.6. □

Lemmas B.5.9, B.5.10, and B.5.11 below are intermediate results that are used in the proof of Proposition 2.4.3.

**Lemma B.5.9.** *When auditing jointly, the buyers are better-off auditing the common supplier than auditing one independent supplier. Further, there exists a threshold $\hat{K}$ such that if the auditing fixed cost $K < \hat{K}$, then the buyers are better-off jointly auditing the common supplier than auditing no supplier.*

**Proof of Lemma B.5.9:** We first show that it is better for the buyers to jointly audit $S_c$ than to jointly audit one independent supplier, say $S_1$. The aggregate expected profit function of the buyers when they jointly audit $S_c$ can be expressed as:

$$\Pi^b(0, e_{cc}, 0) = \Pi_1^b(0, e_{cc}; 0, 0) + \Pi_2^b(0, 0; 0, e_{cc}).$$

Note that, in joint auditing, the auditing cost is incurred by the coalition instead of a single buyer. The aggregate expected profit function of the buyers when they jointly audit $S_1$ can be expressed as:

$$\Pi^b(e_{c1}, 0, 0) = \Pi_1^b(e_{c1}, 0; 0, 0) + \Pi_2^b(0, 0; e_{c1}, 0).$$

We claim that $\Pi^b(0, e_{cc}^*, 0) \geq \Pi^b(0, e_{c1}^*, 0) \geq \Pi^b(e_{c1}^*, 0, 0)$, where $e_{cc}^*$ (resp., $e_{c1}^*$) is the coalition's optimal effort in jointly auditing $S_c$ (resp., $S_1$). The first inequality follows since $\Pi^b(0, e_{cc}^*, 0) = \max_{e_{cc}} \Pi^b(0, e_{cc}, 0) \geq \Pi^b(0, e_{c1}^*, 0)$. Recall from Section 2.3 that $\pi^b(id_M, jd_M)$ denotes the aggregate *ex post* profit of the two buyers when buyer $B_1$ (resp., $B_2$) has $i$ (resp., $j$) suppliers who are identified in public as being socially irresponsible; $i, j \in \{0, 1, 2\}$. We have

$$\begin{aligned}\Pi^b(0, e_{c1}^*, 0) - \Pi^b(e_{c1}^*, 0, 0) =& r(1-e)\big[1 - r(1-e)\big]e_{c1}^* \left[\pi^b(d_M, 0) - \pi^b(d_M, d_M)\right] + \\ & \big[r(1-e)\big]^2 e_{c1}^* \left[\pi^b(d_M, d_M) - \pi^b(2d_M, d_M)\right] \geq 0,\end{aligned}$$

since $\pi^b(d_M, 0) - \pi^b(d_M, d_M) \geq 0$ and $\pi^b(d_M, d_M) - \pi^b(2d_M, d_M) \geq 0$. The other case of jointly auditing $S_2$ is symmetric.

The two buyers choose to cooperate in auditing only if cooperation is better than auditing no supplier. Let $\hat{K}$ denote the difference in the coalition's optimal profit from auditing the common supplier, assuming the fixed auditing cost $K = 0$, and the optimal profit from auditing no supplier. That is,

$$\hat{K} \triangleq \Pi^b(0, e_{cc}^*, 0)\big|_{K=0} - \Pi^b(0, 0, 0) \geq 0.$$

It follows immediately that if $K < \hat{K}$, then it is better for the buyers to jointly audit the common supplier than to audit no supplier. □

**Lemma B.5.10.** *It is better for the buyers to jointly audit the common supplier and an independent supplier than to jointly audit both independent suppliers.*

**Proof of Lemma B.5.10:** Suppose that the buyers jointly audit the common supplier $S_c$ and the independent supplier $S_1$. The buyers choose their auditing efforts $e_{c1}$ and $e_{cc}$ to maximize their aggregate expected profit, which can be expressed as follows:

$$\Pi^b(e_{c1}, e_{cc}, 0) = \Pi_1^b(e_{c1}, 0; 0, e_{cc}) + \Pi_2^b(0, e_{cc}; e_{c1}, 0).$$

Let the corresponding optimal auditing efforts be $\hat{e}_{c1}$ and $\hat{e}_{cc}$. If, instead, the buyers jointly audit the two independent suppliers ($S_1$ and $S_2$), then the buyers' aggregate profit function can be expressed as follows:

$$\Pi^b(e_{c1}, 0, e_{c2}) = \Pi_1^b(e_{c1}, 0; e_{c2}, 0) + \Pi_2^b(e_{c2}, 0; e_{c1}, 0).$$

It is straightforward to show that, in this case, the optimal efforts $\tilde{e}_{c1}$ and $\tilde{e}_{c2}$ in auditing $S_1$ and $S_2$, respectively, are the same; i.e., $\tilde{e}_{c1} = \tilde{e}_{c2} = e_a$. We claim that $\Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0) \geq \Pi^b(e_a, e_a, 0) \geq \Pi^b(e_a, 0, e_a)$, implying that the buyers are better-off from jointly auditing $S_1$

and $S_c$ than from jointly auditing $S_1$ and $S_2$. The first inequality follows since $\Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0) = \max_{e_{c1}, e_{cc}} \Pi^b(e_{c1}, e_{cc}, 0)$. The second inequality holds since

$$\Pi^b(e_a, e_a, 0) - \Pi^b(e_a, 0, e_a) = \big[1 - r(1-e)(1-e_a)\big] r(1-e)e_a \left[\pi^b(d_M, 0) - \pi^b(d_M, d_M)\right] + \big[r(1-e)\big]^2 (1-e_a)e_a \left[\pi^b(d_M, d_M) - \pi^b(2d_M, 2d_M)\right] \geq 0,$$

since $\pi^b(d_M, 0) - \pi^b(d_M, d_M) \geq 0$ and $\pi^b(d_M, d_M) - \pi^b(2d_M, 2d_M) \geq 0$. □

**Lemma B.5.11.** *There exists a threshold $\tilde{K}$ such that if the auditing fixed cost $K < \tilde{K}$, then it is better for the buyers to jointly audit the common supplier and an independent supplier than to jointly audit only the common supplier.*

**Proof of Lemma B.5.11:** First, let us assume that $K = 0$. When the buyers jointly audit the independent supplier $S_1$ and the common supplier $S_c$, let the corresponding optimal auditing efforts be $\hat{e}_{c1}$ and $\hat{e}_{cc}$, respectively. Analogously, when the buyers jointly audit only the common supplier $S_c$, then let the optimal auditing effort be $e^*_{cc}$. Then, we have

$$\Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0)\big|_{K=0} = \max_{e_{c1}, e_{cc}} \Pi^b(e_{c1}, e_{cc}, 0)\big|_{K=0} \geq \Pi^b(0, e^*_{cc}, 0)\big|_{K=0}.$$

Let

$$\tilde{K} \triangleq \Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0)\big|_{K=0} - \Pi^b(0, e^*_{cc}, 0)\big|_{K=0} \geq 0.$$

Now, if the auditing fixed cost is $K < \tilde{K}$, we have

$$\Pi^b(0, e^*_{cc}, 0)\big|_{K=0} - K < \Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0)\big|_{K=0} - 2K.$$

That is, it is better for the buyers to jointly audit both the common supplier and $S_1$ than to jointly audit only the common supplier. □

**Proof of Proposition 2.4.3:** We establish the proposition by (1) deriving the fair share of the auditing cost between the buyers in the coalition, (2) deriving the conditions under which jointly auditing the common supplier and an independent supplier (resp., jointly auditing only the common supplier, jointly auditing none of the suppliers) gives the buyers the highest aggregate profit, and (3) showing that the coalition of the two buyers is stable. We focus on the scenario in which at least one supplier is audited in equilibrium under unilateral auditing. The proof for the case where no supplier is audited is trivial and omitted for brevity.

(1) We first use the notion of Shapley value to decide the fair share of the auditing cost for each buyer in the coalition. We present the analysis for the case where both $S_c$ and $S_1$ are jointly audited; the analysis for the case where only $S_c$ is jointly audited is similar. When the buyers jointly audit $S_c$ and $S_1$, denote their optimal aggregate profit by $\Pi^{b*}(S_1 + S_c)$. When the buyers unilaterally audit their suppliers, there exist two types of equilibria in which at least one supplier is audited (see Proposition 2.4.2): (A) each buyer audits his independent supplier with an effort of $e_I^*$, and (B) one buyer audits his independent supplier with an effort of $\hat{e}_I$ and the other does not audit any supplier. In what follows, we show the analysis for the first equilibrium. The analysis for the equilibria of type B is similar and therefore omitted for brevity. Let us denote the expected profit of buyer $B_i$ under unilateral auditing by $\Pi_i^{b*}$, $i \in \{1, 2\}$.

If the buyers jointly audit $S_1$ and $S_c$, then the Shapley value for $B_i$, where $i, j \in \{1, 2\}, i \neq j$, is:

$$\phi_i = \frac{1}{2}\Pi_i^{b*} + \frac{1}{2}(\Pi^{b*}(S_1 + S_c) - \Pi_j^{b*}).$$

Since $\Pi_1^{b*} = \Pi_2^{b*}$, the Shapley values for $B_1$ and $B_2$ are the same (i.e., $\phi_1 = \phi_2$). To fairly share the auditing cost, the buyers need to split the auditing cost such that they gain equal expected profit from joint-auditing. Let us denote the share of the optimal expected profit (excluding the auditing cost) of $B_1$ and $B_2$ by $R_1^b(e_{c1}^*, e_{cc}^*)$ and $R_2^b(e_{c1}^*, e_{cc}^*)$, respectively. Let the share of the auditing cost of $B_1$ and $B_2$ be $\Gamma_1$ and $\Gamma_2$, respectively. Then, for a fair cost-sharing, we should satisfy

$$\Gamma_1 + \Gamma_2 = \sum_{j=1,c} [K\mathbb{1}_{e_{cj}^*>0} + K_a(e_{cj}^*)];$$

$$R_1^b(e_{c1}^*, e_{cc}^*) - \Gamma_1 = R_2^b(e_{c1}^*, e_{cc}^*) - \Gamma_2.$$

Let $\Delta\Pi = R_1^b(e_{c1}^*, e_{cc}^*) - R_2^b(e_{c1}^*, e_{cc}^*)$. Then,

$$\Gamma_1 = \frac{1}{2}\left[\sum_{j=1,c}\left[K\mathbb{1}_{e_{cj}^*>0} + \frac{a}{2}(e_{cj}^*)^2\right] + \Delta\Pi\right] \text{ and } \Gamma_2 = \frac{1}{2}\left[\sum_{j=1,c}\left[K\mathbb{1}_{e_{cj}^*>0} + \frac{a}{2}(e_{cj}^*)^2\right] - \Delta\Pi\right].$$

Note that $B_1$, who directly sources from $S_1$, pays $\Delta\Pi$ more than $B_2$.

(2) To derive the conditions under which jointly auditing $S_c$ and $S_1$ (resp., jointly auditing $S_c$, jointly auditing none of the suppliers) gives the buyers the highest aggregate profit, we combine the results of Lemmas B.5.9, B.5.10, and B.5.11; recall the parametric constants $\hat{K}$ and $\tilde{K}$ from the proofs of these results.

- If $\tilde{K} < \hat{K}$, then (a) If $K < \tilde{K}$, then jointly auditing $S_c$ and $S_1$ gives the buyers the highest expected profit. (b) If $K \in [\tilde{K}, \hat{K})$, then jointly auditing $S_c$ gives the buyers the highest expected profit. (c) If $K \geq \hat{K}$, then auditing no supplier is best for the buyers.

- If $\tilde{K} \geq \hat{K}$, then (a) If $K < \frac{\hat{K}+\tilde{K}}{2}$, then jointly auditing $S_c$ and $S_1$ gives the buyers the highest expected profit. (b) If $K \geq \frac{\hat{K}+\tilde{K}}{2}$, then auditing no supplier is best for the buyers, since the difference in profit (excluding the fixed cost) between jointly auditing $S_c$ and $S_1$ and auditing no supplier equals $\hat{K} + \tilde{K}$.

Letting $K_c^L = \min\{\frac{\hat{K}+\tilde{K}}{2}, \tilde{K}\}$ and $K_c^H = \max\{\frac{\hat{K}+\tilde{K}}{2}, \hat{K}\}$, we obtain the following conditions:

- If the auditing fixed cost $K < K_c^L$, then jointly auditing the common supplier $S_c$ along with the independent supplier $S_1$ yields the highest aggregate profit for the buyers. In this case, the difference between the expected profits of $B_1$ and $B_2$ (excluding auditing costs) is $\Delta\Pi > 0$.

- If $K_c^L \le K < K_c^H$, then jointly auditing only the common supplier yields the highest aggregate profit for the buyers. In this case, $\Delta\Pi = 0$.

- If $K \ge K_c^H$, then no auditing yields the highest aggregate profit for the buyers.

(3) We establish the stability of the coalition by showing that the buyers have no incentive to deviate from joint-auditing to unilaterally make their auditing decisions. We show the analysis for the case where the auditing fixed cost $K < K_c^L$ and it is optimal for the buyers to jointly audit both $S_c$ and $S_1$; the analysis for each of the other cases is similar.

First, observe that the buyers' optimal aggregate profit from jointly auditing $S_c$ and $S_1$ is larger than that from jointly auditing $S_1$ and $S_2$, since $\Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0) \ge \Pi^b(\tilde{e}_{c1}, 0, \tilde{e}_{c2})$ by Lemma B.5.10, where $\hat{e}_{c1}$ and $\hat{e}_{cc}$ (resp., $\tilde{e}_{c1}$ and $\tilde{e}_{c2}$) are the optimal efforts of jointly auditing $S_1$ and $S_c$ (resp., $S_1$ and $S_2$). Second, observe that jointly-auditing two independent suppliers yields higher profits for the buyers than unilaterally auditing, since $\Pi^b(\tilde{e}_{c1}, 0, \tilde{e}_{c2}) = \max_{e_{11}, e_{22}} \left[\Pi_1^b(e_{11}, 0; e_{22}, 0) + \Pi_2^b(e_{22}, 0; e_{11}, 0)\right] \ge \Pi_1^b(e_I^*, 0; e_I^*, 0) + \Pi_2^b(e_I^*, 0; e_I^*, 0)$, where the optimal joint-auditing efforts $\tilde{e}_{c1} = \tilde{e}_{c2}$ from Lemma B.5.10, and the unilateral equilibrium auditing effort is $e_I^*$ from Proposition 2.4.2. Finally, note that each buyer has the same expected joint-auditing profit (half of $\Pi^b(\hat{e}_{c1}, \hat{e}_{cc}, 0)$) using the proof of part (1), and the same expected unilateral-auditing profit ($\Pi_1^b(e_I^*, 0; e_I^*, 0) = \Pi_2^b(e_I^*, 0; e_I^*, 0)$). Thus, the profit of each buyer from joint-auditing is larger than that from unilateral-auditing, making the joint-auditing coalition stable. □

Lemma 2.5.1 can be verified using standard algebraic calculations; we therefore omit its proof for brevity. To establish Proposition 2.5.1, we first prove the following lemma regarding the comparison between the total auditing efforts under unilateral and joint auditing. Recall that in the scenario being considered here, the auditing fixed cost $K < \min\{K_u^L, K_c^L\}$; in this case, two suppliers are audited under both unilateral and joint auditing.

**Lemma B.5.12.** *If $\beta < \frac{2}{3}$, then the difference between the total auditing effort under joint auditing, namely $e^*_{c1} + e^*_{cc}$, and the total auditing effort under unilateral auditing, namely $2e^*_I$, is bounded from below by a strictly positive constant $C_o$ and bounded from above by 2, i.e.,*

$$2 > e^*_{c1} + e^*_{cc} - 2e^*_I > C_o > 0.$$

**Proof of Lemma B.5.12:** We first recall that, under unilateral auditing, if $B_1$ audits $S_1$ and $B_2$ audits $S_2$, then $B_1$'s best-response auditing effort $e^*_{11}(e_{22})$, defined in (B.9), strictly decreases in $e_{22}$ (see the proof of Lemma B.5.7). Thus, noticing that the equilibrium unilateral auditing effort $e^*_I$ satisfies $e^*_I = e^*_{11}(e^*_I)$, we have

$$e^*_I < e^*_{11}(0). \tag{B.16}$$

When $B_1$ and $B_2$ jointly audit $S_1$ and $S_c$, the first-order conditions for the optimal auditing efforts are:

$$\begin{aligned}
e^{**}_{c1}(e_{cc}) = \; & \frac{r(1-e)\big[1-r(1-e)(1-e_{cc})\big]\big[1-r(1-e)\big]}{a}\big[\pi^b(0,0)-\pi^b(d_M,0)\big]+ \\
& \frac{\big[r(1-e)\big]^2\big[1-r(1-e)(1-e_{cc})\big]}{a}\big[\pi^b(d_M,0)-\pi^b(d_M,d_M)\big]\,; \\
e^{**}_{cc}(e_{c1}) = \; & \frac{r(1-e)\big[1-r(1-e)(1-e_{c1})\big]\big[1-r(1-e)\big]}{a}\pi^b(0,0)+ \\
& \frac{\big[r(1-e)\big]^2\big[2-2r(1-e)(1-e_{c1})-e_{c1}\big]}{a}\pi^b(d_M,0)- \\
& \frac{r(1-e)\big[1-r(1-e)(1-e_{c1})r(1-e)\big]}{a}\pi^b(d_M,d_M).
\end{aligned}$$

Observe that $e^{**}_{c1}(e_{cc})$ increases in $e_{cc}$ and $e^{**}_{cc}(e_{c1})$ increases in $e_{c1}$, since

$$\begin{aligned}
\frac{\partial e^{**}_{c1}(e_{cc})}{\partial e_{cc}} = \frac{\partial e^{**}_{cc}(e_{c1})}{\partial e_{c1}} = & \frac{\big[r(1-e)\big]^2\big[1-r(1-e)\big]}{a}\big[\pi^b(0,0)-\pi^b(d_M,0)\big]+ \\
& \frac{\big[r(1-e)\big]^3}{a}\big[\pi^b(d_M,0)-\pi^b(d_M,d_M)\big] \geq 0.
\end{aligned}$$

Thus, noticing that the optimal joint auditing efforts satisfy $e^*_{c1} = e^{**}_{c1}(e^*_{cc})$ and $e^*_{cc} = e^{**}_{cc}(e^*_{c1})$, we have

$$e^*_{c1} + e^*_{cc} = e^{**}_{c1}(e^*_{cc}) + e^{**}_{cc}(e^*_{c1}) \geq e^{**}_{c1}(0) + e^{**}_{cc}(0). \tag{B.17}$$

Thus, using (B.16) and (B.17), when $\beta < \frac{2}{3}$, we have

$$\begin{aligned} & e^*_{c1} + e^*_{cc} - 2e^*_I > e^{**}_{c1}(0) + e^{**}_{cc}(0) - 2e^*_{11}(0) \\ & = \frac{r(1-e)\big[1 - r(1-e)\big]d_M}{a(2-\beta)^2(2+\beta)^2}\left\{(2-3\beta)(2-\beta)\big[2(\alpha - 2w) - d_M\big] + 8r(1-e)\beta d_M\right\} > 0. \end{aligned}$$

The last inequality follows from the inequality $\alpha - 2w \geq d_M$ (Section 2.3) and the fact that $r(1-e) \in (0,1)$. Thus, the strictly-positive lower bound on the difference in total auditing effort between joint and unilateral auditing is obtained by defining

$$C_o \triangleq \frac{r(1-e)\big[1 - r(1-e)\big]d_M}{a(2-\beta)^2(2+\beta)^2}\left\{(2-3\beta)(2-\beta)\big[2(\alpha - 2w) - d_M\big] + 8r(1-e)\beta d_M\right\}.$$

The upper bound of 2 follows trivially since the auditing efforts are in $(0,1)$. □

**Proof of Proposition 2.5.1:** Statement (i) follows immediately from Lemma B.5.12. We now establish Statement (ii). For ease of exposition, we define the following notation, where $\Pi^{sw}_u(e_I, 0, e_I, 0)$ and $\Pi^{sw}_c(e_{c1}, e_{cc}, 0)$ are as defined in (B.1) and (B.2), respectively.

$$\begin{aligned} & \tilde{\Pi}^{sw}_u(e_I, 0, e_I, 0) \triangleq \Pi^{sw}_u(e_I, 0, e_I, 0) + \big[\lambda_C(0,0) + 2\lambda_I(e_I)\big]d_S + 2(1-e)e_I\hat{d}_S; \\ & \tilde{\Pi}^{sw}_c(e_{c1}, e_{cc}, 0) \triangleq \Pi^{sw}_c(e_{c1}, e_{cc}, 0) + \big[\lambda_I(e_{c1}) + \lambda_I(e_{cc}) + \lambda_I(0)\big]d_S + (1-e)(e_{c1} + e_{cc})\hat{d}_S. \end{aligned}$$

Since all the auditing efforts are bounded (specifically, in $(0,1)$), both $\tilde{\Pi}^{sw}_u(e_I, 0, e_I, 0)$ and $\tilde{\Pi}^{sw}_c(e_{c1}, e_{cc}, 0)$ are also bounded. In addition, neither $\tilde{\Pi}^{sw}_u(e_I, 0, e_I, 0)$ nor $\tilde{\Pi}^{sw}_c(e_{c1}, e_{cc}, 0)$ depends on $d_S$ or $\hat{d}_S$. Let

$$\Delta\tilde{\Pi}^{sw} \triangleq \sup_{e_I, e_{c1}, e_{cc}} \left\{\tilde{\Pi}^{sw}_u(e_I, 0, e_I, 0) - \tilde{\Pi}^{sw}_c(e_{c1}, e_{cc}, 0)\right\}. \tag{B.18}$$

Then, the difference between the equilibrium social welfare under joint and unilateral auditing is:

$$\begin{aligned}
& \Pi_c^{sw}(e_{c1}^*, e_{cc}^*, 0) - \Pi_u^{sw}(e_I^*, 0, e_I^*, 0) \\
= & \Big\{\tilde{\Pi}_c^{sw}(e_{c1}^*, e_{cc}^*, 0) - \big[\lambda_I(e_{c1}^*) + \lambda_I(e_{cc}^*) + \lambda_I(0)\big]d_S - (1-e)(e_{c1}^* + e_{cc}^*)\hat{d}_S\Big\} - \\
& \Big\{\tilde{\Pi}_u^{sw}(e_I^*, 0, e_I^*, 0) - \big[\lambda_C(0,0) - 2\lambda_I(e_I^*)\big]d_S - 2(1-e)e_I^*\hat{d}_S\Big\} \\
= & (1-e)(e_{c1}^* + e_{cc}^* - 2e_I^*)\big(rd_S - \hat{d}_S\big) + \tilde{\Pi}_c^{sw}(e_{c1}^*, e_{cc}^*, 0) - \tilde{\Pi}_u^{sw}(e_I^*, 0, e_I^*, 0) \\
> & (1-e)(e_{c1}^* + e_{cc}^* - 2e_I^*)\big(rd_S - \hat{d}_S\big) - \Delta\tilde{\Pi}^{sw},
\end{aligned}$$

where the last inequality follows from (B.18). From Lemma B.5.12, we have

$$2 > e_{c1}^* + e_{cc}^* - 2e_I^* > C_o > 0.$$

Let

$$\Delta_S \triangleq \max\left\{\frac{\Delta\tilde{\Pi}^{sw}}{C_o(1-e)}, \frac{\Delta\tilde{\Pi}^{sw}}{2(1-e)}\right\}.$$

Thus, if $rd_S - \hat{d}_S \geq \Delta_S$, then $\Pi_c^{sw}(e_{c1}^*, e_{cc}^*, 0) - \Pi_u^{sw}(e_I^*, 0, e_I^*, 0) > 0$. That is, the social welfare under joint auditing is higher than that under unilateral auditing. □

**Proof of Lemma 2.6.1** We use Theorem 1.2 of Fudenberg and Tirole (1991) to show that there exists a pure-strategy Nash equilibrium of the auditing decisions of the two buyers when they unilaterally audit the suppliers. First, the strategy spaces of the buyers are nonempty, compact, and convex subsets of $\mathbb{R}$ since buyer $B_i$'s effort in auditing his independent supplier $S_i$ is $e_{ii} \in [0, \bar{e}]$, for $i \in \{1, 2\}$. Second, each buyer's expected profit function is continuous and concave in his effort in auditing his respective independent supplier. The second-order condition of buyer $B_1$'s expected profit $\Pi_1^b(e_{11}, \bar{e} - e_{11}; e_{22}, \bar{e} - e_{22})$ with respect to $e_{11}$ is

$$\begin{aligned}
&\frac{\partial^2 \Pi_1^b(e_{11}, \bar{e} - e_{11}; e_{22}, \bar{e} - e_{22})}{\partial e_{11}^2} \\
=& -2a + \frac{8[r(1-e)]^2(1-\bar{e}+e_{22})}{(4-\beta^2)^2}\Big\{d_M\big[d_M + 2(1-\beta)w + 2\hat{w} - \\
&(2-\beta)\alpha - (2-\beta)(\hat{w}-w) - \beta r(1-e)(1-e_{22})d_M - \\
&2\beta r(1-e)(1-e_{22})(\hat{w}-w)\big] - (2-\beta)(\hat{w}-w)^2\Big\} < 0,
\end{aligned}$$

where the strict inequality follows from the condition (in Section 2.3) which ensures that the buyers order positive amounts, namely $(2-\beta)\alpha - 2d_M > 2(1-\beta)w + 2\hat{w}$. The case for buyer $B_2$ is symmetric. □

**Proof of Proposition 2.6.1:** Notice that each buyer's expected profit function is concave in his effort in auditing his respective independent supplier. The cross derivative of $B_1$'s expected profit function with respect to his effort in auditing the independent supplier and $\alpha$, given that both buyers audit their independent suppliers with the maximum auditing resource $\bar{e}$, is

$$\begin{aligned}
&\frac{\partial^2 \Pi_1^b(e_{11}, \bar{e} - e_{11}; e_{22}, \bar{e} - e_{22})}{\partial e_{11} \partial \alpha}\Bigg|_{e_{11}=e_{22}=\bar{e}} \\
=&\frac{2r(1-e)}{(2+\beta)^2(2-\beta)}\Bigg\{\Big\{\big[1-r(1-e)(1-\bar{e})\big]\beta - 2r(1-e)\bar{e}\Big\}d_M + \\
&\Big\{\Big\{\big[1-r(1-e)(1-\bar{e})\big]^2 + \big[r(1-e)(1-\bar{e})\big]^2\Big\}\beta + 4r(1-e)(1-\bar{e})\Big\}(\hat{w}-w)\Bigg\} > 0,
\end{aligned}$$

if $\bar{e} < \frac{\beta[1-r(1-e)]}{(2-\beta)r(1-e)}$. Therefore, there exist thresholds $\alpha_u$ and $\bar{e}_u = \frac{\beta[1-r(1-e)]}{(2-\beta)r(1-e)}$ such that, when $\alpha > \alpha_u$ and $\bar{e} < \bar{e}_u$, we have $\frac{\partial \Pi_1^b(e_{11}, \bar{e}-e_{11}; \bar{e}, 0)}{\partial e_{11}} > 0$ for $e_{11} \in [0, \bar{e}]$. The case of buyer $B_2$ is symmetric. □

**Proof of Proposition 2.6.2:** By the sufficient conditions derived in Appendix B.4 to ensure the joint-concavity of the coalition's profit function, there exist thresholds $a_c$ and $\alpha_c^1$ such that, when the auditing variable-cost parameter $a > a_c$ and the MWTP parameter $\alpha > \alpha_c^1$, the coalition's profit function is jointly concave in the auditing efforts $(e_{c1}, e_{c2})$. Therefore, since the coalition's profit function is symmetric in the auditing efforts $(e_{c1}, e_{c2})$, we can assume symmetric optimal auditing decisions. Setting $e_{c2} = e_{c1}$ in the buyers' coalition's profit function, we get

$$\frac{\partial^2 \Pi^b(e_{c1}, 2\bar{e} - 2e_{c1}, e_{c1})}{\partial e_{c1} \partial \alpha} = -\frac{4r(1-e)\Big\{d_M\big[1 - r(1-e)(1 - 4e_{c1} + 2\bar{e})\big] + \hat{w} - w\Big\}}{(2+\beta)^2} < 0,$$

if $\bar{e} < \frac{1-r(1-e)}{2r(1-e)}$. Thus, there exist thresholds $\alpha_c^2$ and $\bar{e}_c = \frac{1-r(1-e)}{2r(1-e)}$ such that, when $\alpha > \alpha_c^2$ and $\bar{e} < \bar{e}_c$, $\frac{\partial \Pi^b(e_{c1}, 2\bar{e} - 2e_{c1}, e_{c1})}{\partial e_{c1}} < 0$, implying that the coalition allocates a positive amount of its pooled auditing resource to audit the common supplier in the optimal solution. To combine the two conditions above, we let $\alpha_c = \max\{\alpha_c^1, \alpha_c^2\}$; the claimed result now follows. □

**Proof of Corollary 2.6.1:** Using Propositions 2.6.1 and 2.6.2, let $\hat{\alpha} = \max\{\alpha_u, \alpha_c\}$ and $\hat{e} = \min\{\bar{e}_u, \bar{e}_c\}$. The result now follows immediately. □

## APPENDIX C

## PROOF OF THE RESULTS IN CHAPTER 3

Given the auditing-effort vector $(e_{11}, e_{1c}, e_{22}, e_{2c})$ and responsibility-effort vector $(e_1^r, e_c^r, e_2^r)$, we denote the expected profit functions of $B_1$ and $B_2$ by $\Pi_1^b(e_{11}, e_{1c}; e_{22}, e_{2c}, e_1^r, e_c^r, e_2^r)$ and $\Pi_2^b(e_{22}, e_{2c}; e_{11}, e_{1c}, e_1^r, e_c^r, e_2^r)$, respectively. Let us denote the expected profit functions of $S_1$, $S_c$, and $S_2$ by $\Pi_1^s(e_1^r; e_c^r, e_2^r, e_{11}, e_{1c}, e_{22}, e_{2c})$, $\Pi_c^s(e_c^r; e_1^r, e_2^r, e_{11}, e_{1c}, e_{22}, e_{2c})$, and $\Pi_2^s(e_2^r; e_1^r, e_c^r, e_{11}, e_{1c}, e_{22}, e_{2c})$. When no confusion arises in doing so, we simplify this notation to $\Pi_j^s(e_j^r)$, $j \in \{1, c, 2\}$, respectively. When the two buyers audit jointly, we denote their aggregate profit function by $\Pi^b(e_{c1}, e_{cc}, e_{c2}; e_1^r, e_c^r, e_2^r)$. To ensure that the supplier's best-response social-responsibility effort is in the interior of its domain, we require that the cost of this effort is sufficiently convex; this is guaranteed if $b > \frac{2}{3} r d_M w + r d_s + \hat{d}_S$ (see Chapter 3).

The *ex ante* likelihood that an independent supplier $S_j$ causes MWTP damage to her buyer $B_i$ and therefore incurs cost $d_S$, is $\lambda_I^N(e_{ij}, e_j^r) \triangleq r(1 - e_j^r)(1 - e_{ij})$, where $i = j$ and $i, j \in \{1, 2\}$; the *ex ante* likelihood that the common supplier $S_c$ causes MWTP damage to her buyer $B_1$ ($B_2$) and therefore incurs cost $d_S$, is $\lambda_C^N(e_{1c}, e_{2c}, e_c^r) \triangleq r(1-e_c^r)(1-e_{1c})(1-e_{2c})$. Similarly, the *ex ante* likelihood that an independent supplier $S_j$ is identified for responsibility violations through an audit by buyer $B_i$ and therefore incurs cost $\hat{d}_S$ is $\eta_I^N(e_{ij}, e_j^r) = (1-e_j^r)e_{ij}$, where $i = j$ and $i, j \in \{1, 2\}$; the *ex ante* likelihood that the common supplier $S_c$ is identified for responsibility violations through an audit by buyer $B_1$ ($B_2$) and therefore incurs cost $\hat{d}_S$, is $\eta_C^N(e_{1c}, e_{2c}, e_c^r) \triangleq (1 - e_c^r)\big[1 - (1 - e_{1c})(1 - e_{2c})\big]$. Using this notation, the expected profit of buyer $B_1$ is:

$$
\begin{aligned}
&\Pi_1^b(e_{11}, e_{1c}; e_{22}, e_{2c}, e_1^r, e_c^r, e_2^r)\\
=&\left[1-\lambda_I^N(e_{11},e_1^r)\right]\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]\left[1-\lambda_I^N(e_{22},e_2^r)\right]\left(\frac{\alpha-2w}{3}\right)^2+\\
&\left[1-\lambda_I^N(e_{11},e_1^r)\right]\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]\lambda_I^N(e_{22},e_2^r)\left(\frac{\alpha-2w+d_M}{3}\right)^2+\\
&\left\{\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]\lambda_I^N(e_{11},e_1^r)\lambda_I^N(e_{22},e_2^r)+\lambda_C^N(e_{1c},e_{2c},e_c^r)\right\}\left(\frac{\alpha-2w-d_M}{3}\right)^2+\\
&\lambda_I^N(e_{11},e_1^r)\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]\left[1-\lambda_I^N(e_{22},e_2^r)\right]\left(\frac{\alpha-2w-2d_M}{3}\right)^2-\\
&\left[K\mathbb{1}_{e_{11}>0}+\frac{a}{2}\left(e_{11}\right)^2\right]-\left[K\mathbb{1}_{e_{1c}>0}+\frac{a}{2}\left(e_{1c}\right)^2\right].
\end{aligned}
$$

The expected profit of buyer $B_2$ is symmetric. The expected profit of supplier $S_1$ is:

$$
\begin{aligned}
&\Pi_1^s(e_1^r; e_c^r, e_2^r, e_{11}, e_{1c}, e_{22}, e_{2c})\\
=&\left[1-\lambda_I^N(e_{11},e_1^r)\right]w\left\{\frac{\alpha-2w}{3}+\left\{\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]\lambda_I^N(e_{22},e_2^r)-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right\}\frac{d_M}{3}\right\}+\\
&\lambda_I^N(e_{11},e_1^r)\left\{w\left\{\frac{\alpha-2w}{3}-\left\{1+\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]\left[1-\lambda_I^N(e_{22},e_2^r)\right]\right\}\frac{d_M}{3}\right\}-d_S\right\}-\\
&\eta_I^N(e_{11},e_1^r)\hat{d}_S-K_r(e_1^r).
\end{aligned}
$$

The expected profit of supplier $S_2$ is symmetric. The expected profit of supplier $S_c$ is:

$$
\begin{aligned}
&\Pi_c^s(e_c^r; e_1^r, e_2^r, e_{11}, e_{1c}, e_{22}, e_{2c})\\
=&\left[1-\lambda_C^N(e_{1c},e_{2c},e_c^r)\right]w\left\{\frac{2(\alpha-2w)}{3}-\left[\lambda_I^N(e_{11},e_1^r)+\lambda_I^N(e_{22},e_2^r)\right]\frac{d_M}{3}\right\}+\\
&\lambda_C^N(e_{1c},e_{2c},e_c^r)\left[2w\frac{\alpha-2w-d_M}{3}-d_S\right]-\eta_C^N(e_{1c},e_{2c},e_c^r)\hat{d}_S-K_r(e_c^r).
\end{aligned}
$$

**Proof of Proposition 3.1.1:** We analyze the best-response functions of the suppliers. There are four possibilities, depending on which suppliers are audited: $(S_1, S_2)$, $(S_1, S_c)$, $(S_c, S_2)$ and $(S_c, S_c)$. We show the analysis for $(S_1, S_2)$ here; the analysis for each of the other cases is similar and omitted for brevity.

For $(S_1, S_2)$, the best-response responsibility efforts of $S_1$ and $S_2$, respectively, are as follows:

$$e_1^{r*}(e_{11}, e_c^r) = \frac{1}{b}\left\{2r(1-e_{11})\big[1-r(1-e_c^r)\big]w\frac{d_M}{3} + e_{11}\hat{d}_S + r(1-e_{11})d_S\right\};$$

$$e_2^{r*}(e_{22}, e_c^r) = \frac{1}{b}\left\{2r(1-e_{22})\big[1-r(1-e_c^r)\big]w\frac{d_M}{3} + e_{22}\hat{d}_S + r(1-e_{22})d_S\right\}.$$

To guarantee the effectiveness of an audit – i.e., an increase in a buyer's auditing effort induces an increase in the responsibility effort of the audited supplier – we need $\frac{\partial e_1^{r*}(e_{11},e_c^r)}{\partial e_{11}} = \frac{\partial e_2^{r*}(e_{22},e_c^r)}{\partial e_{22}} = \frac{1}{b}\{-2r\big[1-r(1-e_c^r)\big]w\frac{d_M}{3} + \hat{d}_S - rd_S\} > 0$ for all $e_c^r \in [0,1]$, which holds if $\hat{d}_S > \frac{2}{3}rwd_M + rd_S = \overline{d}_S$. □

**Proof of Proposition 3.1.2:** We establish the result by showing that the cross-partial derivative of a supplier's profit with respect to its own responsibility effort and the responsibility effort of the other supplier associated with the same buyer, is positive.

For brevity, we discuss the case when $S_1$ and $S_2$ are audited; the analysis for each of the other cases is similar. The cross-partial derivative of $S_1$'s expected profit with respect to $e_1^r$ and $e_c^r$ is $\frac{\partial^2 \Pi_1^s(e_1^r)}{\partial e_1^r \partial e_c^r} = \frac{2}{3}r^2(1-e_{11})wd_M > 0$; the cross-partial derivative of $S_c$'s expected profit with respect to $e_c^r$ and $e_1^r$ (resp., $e_c^r$ and $e_2^r$) is $\frac{\partial^2 \Pi_c^s(e_c^r)}{\partial e_c^r \partial e_1^r} = \frac{1}{3}r^2(1-e_{11})wd_M > 0$ (resp., $\frac{\partial^2 \Pi_c^s(e_c^r)}{\partial e_c^r \partial e_2^r} = \frac{1}{3}r^2(1-e_{22})wd_M > 0$); the cross-partial derivative of $S_2$'s expected profit with respect to $e_2^r$ and $e_c^r$ is $\frac{\partial^2 \Pi_2^s(e_2^r)}{\partial e_2^r \partial e_c^r} = \frac{2}{3}r^2(1-e_{22})wd_M > 0$. Thus, for two suppliers associated with the same buyer, one supplier's marginal profit with respect to her own responsibility effort increases in the other supplier's responsibility effort. Consequently, an increase in one supplier's responsibility effort induces an increase in the best-response responsibility effort of the other. □

**Proof of Proposition 3.1.3:** For brevity, we only show that one buyer auditing the common supplier and the other auditing his independent supplier cannot be sustained in equilibrium when the two buyers unilaterally make auditing decisions and the suppliers' responsibility efforts are endogenous. The proof that both the buyers auditing the common supplier cannot be an equilibrium either is similar.

Suppose $B_1$ audits $S_c$ and $B_2$ audits $S_2$. Let the corresponding best-response auditing and responsibility efforts be $(0, e_{1c}^*, e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*})$. Keeping all other decisions fixed, let $\hat{e}_{11}$ denote the optimal auditing effort of $B_1$ if he deviates to audit $S_1$. We first establish that $e_2^{r*} > e_1^{r*}$ and $e_c^{r*} > e_1^{r*}$, and then exploit these inequalities to establish that $B_1$ indeed has an incentive to deviate from auditing $S_c$ to audit $S_1$.

- Supplier $S_2$'s best-response effort $e_2^{r*}$ satisfies

$$\begin{aligned} be_2^{r*} =& \frac{2}{3}r(1-e_{22}^*)\big[1-r(1-e_c^{r*})(1-e_{1c}^*)\big]wd_M + e_{22}^*\hat{d}_S + r(1-e_{22}^*)d_S \\ >& \frac{2}{3}rwd_M + rd_S - \frac{2}{3}r^2(1-e_{22}^*)(1-e_c^{r*})(1-e_{1c}^*)wd_M, \end{aligned}$$

where the strict inequality holds since $\hat{d}_S > \overline{d}_S = \frac{2}{3}rwd_M + rd_S$. Also note that $S_1$'s best-response responsibility effort $e_1^{r*}$ satisfies

$$be_1^{r*} = \frac{2}{3}rwd_M + rd_S - \frac{2}{3}r^2(1-e_c^{r*})(1-e_{1c}^*)wd_M.$$

Thus, $b(e_2^{r*} - e_1^{r*}) > \frac{2}{3}r^2(1-e_{1c}^*)(1-e_c^{r*})e_{22}^*wd_M > 0$; i.e., $e_2^{r*} > e_1^{r*}$.

- Since $\hat{d}_S > \frac{2}{3}rwd_M + rd_S$, $S_c$'s best-response responsibility effort satisfies

$$\begin{aligned} be_c^{r*} =& \frac{1}{3}r(1-e_{1c}^*)\Big\{2-\big[r(1-e_2^{r*})(1-e_{22}^*)+r(1-e_1^{r*})\big]\Big\}wd_M + e_{1c}^*\hat{d}_S + r(1-e_{1c}^*)d_S \\ >& \frac{2}{3}rwd_M + rd_S - \frac{1}{3}r^2(1-e_{1c}^*)(1-e_2^{r*})(1-e_{22}^*)wd_M - \frac{1}{3}r^2(1-e_{1c}^*)(1-e_1^{r*})wd_M. \end{aligned}$$

Since $e_2^{r*} > e_1^{r*}$, we have

$$\begin{aligned} be_c^{r*} >& \frac{2}{3}rwd_M + rd_S - \frac{1}{3}r^2(1-e_{1c}^*)(1-e_{22}^*)(1-e_1^{r*})wd_M - \frac{1}{3}r^2(1-e_{1c}^*)(1-e_1^{r*})wd_M \\ =& \frac{2}{3}rwd_M + rd_S - \frac{1}{3}r^2(1-e_{1c}^*)(1-e_1^{r*})wd_M(2-e_{22}^*). \end{aligned}$$

Hence, we have $b(e_c^{r*}-e_1^{r*}) > -\frac{2}{3}r^2(1-e_{1c}^*)wd_M(e_c^{r*}-e_1^{r*})+\frac{1}{3}r^2(1-e_{1c}^*)(1-e_1^{r*})wd_Me_{22}^*$, since $be_1^{r*} = \frac{2}{3}rwd_M + rd_S - \frac{2}{3}r^2(1-e_c^{r*})(1-e_{1c}^*)wd_M$. Therefore,

$$e_c^{r*} - e_1^{r*} > \frac{\frac{1}{3}r^2(1-e_{1c}^*)(1-e_1^{r*})wd_Me_{22}^*}{b+\frac{2}{3}r^2(1-e_{1c}^*)wd_M} > 0.$$

We now show that $B_1$ has an incentive to deviate to audit $S_1$ by observing that

$$\Pi_1^b(\hat{e}_{11}, 0; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*}) \geq \Pi_1^b(e_{1c}^*, 0; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*}) > \Pi_1^b(0, e_{1c}^*; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*}).$$

The first inequality is trivial since

$\Pi_1^b(\hat{e}_{11}, 0; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*}) = \max_{e_{11}} \Pi_1^b(e_{11}, 0; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*})$.

Let $\Upsilon = \Pi_1^b(e_{1c}^*, 0; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*}) - \Pi_1^b(0, e_{1c}^*; e_{22}^*, 0, e_1^{r*}, e_c^{r*}, e_2^{r*})$. Then, the second inequality follows since

$$\begin{aligned}\Upsilon =& \frac{1}{3}\big[1-r(1-e_2^{r*})(1-e_{22}^*)\big]re_{1c}^*(1-e_1^{r*})d_M\big[\frac{2}{3}(\alpha-2w)-d_M\big]\\ &+\frac{4}{9}r(1-e_2^{r*})(1-e_{22}^*)re_{1c}^*(e_c^{r*}-e_1^{r*})(\alpha-2w)d_M\\ &+\frac{1}{9}\big[1-r(1-e_2^{r*})(1-e_{22}^*)\big]re_{1c}^*(e_c^{r*}-e_1^{r*})d_M\big[2(\alpha-2w)-d_M\big] > 0.\end{aligned}$$ □

**Proof of Proposition 3.1.4:** For brevity, we only show that the audit of only one independent supplier cannot be sustained in equilibrium when the two buyers jointly make the auditing decisions and the suppliers' responsibility efforts are endogenous. The proof that the audit of only the two independent suppliers cannot be an equilibrium either is similar.

Suppose $B_1$ and $B_2$ jointly audit $S_1$. Let the corresponding best-response auditing and responsibility efforts be $(e_{c1}^*, 0, 0, e_1^{r*}, e_c^{r*}, e_2^{r*})$. Keeping other decisions fixed, let $\hat{e}_{cc}$ denote the optimal auditing effort of the buyers if they deviate to audit their common supplier $S_c$. We first show that $e_1^{r*} > e_2^{r*}$ and $e_1^{r*} > e_c^{r*}$, and then use these inequalities to show that the buyers have an incentive to deviate from auditing $S_1$ to audit $S_c$. The aggregate expected profit function of $B_1$ and $B_2$ when jointly auditing $S_1$ can be expressed as follows:

$$\Pi^b(e_{c1}, 0, 0; e_1^r, e_c^r, e_2^r) = \Pi_1^b(e_{c1}, 0; 0, 0, e_1^r, e_c^r, e_2^r) + \Pi_2^b(0, 0; e_{c1}, 0, e_1^r, e_c^r, e_2^r).$$

The aggregate expected profit function of $B_1$ and $B_2$ when jointly auditing $S_c$ can be expressed as follows:

$$\Pi^b(0, e_{cc}, 0; e_1^r, e_c^r, e_2^r) = \Pi_1^b(0, e_{cc}; 0, 0, e_1^r, e_c^r, e_2^r) + \Pi_2^b(0, 0; 0, e_{cc}, e_1^r, e_c^r, e_2^r).$$

- Supplier $S_1$'s best-response effort $e_1^{r*}$ satisfies

$$\begin{aligned} be_1^{r*} =& \frac{2}{3}r(1-e_{c1}^*)[1-r(1-e_c^{r*})]wd_M + e_{c1}^*\hat{d}_S + r(1-e_{c1}^*)d_S \\ >& \frac{2}{3}r[1-r(1-e_{c1}^*)(1-e_c^{r*})]wd_M + rd_S, \end{aligned} \tag{C.1}$$

  where the strict inequality holds since $\hat{d}_S > \overline{d}_S = \frac{2}{3}rwd_M + rd_S$. Also, note that $S_2$'s best-response responsibility effort $e_2^{r*}$ satisfies

$$be_2^{r*} = \frac{2}{3}r[1-r(1-e_c^{r*})]wd_M + rd_S.$$

  Thus, $b(e_1^{r*} - e_2^{r*}) > \frac{2}{3}r^2 e_{c1}^*(1-e_c^{r*})wd_M > 0$; i.e., $e_1^{r*} > e_2^{r*}$.

- Using (C.1) and $be_c^{r*} = \frac{1}{3}r[2 - r(1-e_1^{r*})(1-e_{c1}^*) - r(1-e_2^{r*})]wd_M + rd_S$, we have

$$\begin{aligned} b(e_1^{r*} - e_c^{r*}) >& \frac{1}{3}[r^2(1-e_{c1}^*)(1-e_1^{r*}) + r^2(1-e_2^{r*}) - 2r^2(1-e_{c1}^*)(1-e_c^{r*})]wd_M \\ >& \frac{2}{3}r^2(1-e_{c1}^*)(e_c^{r*} - e_1^{r*})wd_M, \end{aligned}$$

  where the second inequality holds since $e_1^{r*} > e_2^{r*}$. Therefore, $\left[b+\frac{2}{3}r^2(1-e_{c1}^*)wd_M\right](e_1^{r*} - e_c^{r*}) > 0$; i.e., $e_1^{r*} > e_c^{r*}$.

We now show that the two buyers have an incentive to deviate by establishing that

$$\Pi^b(0, \hat{e}_{cc}, 0; e_1^{r*}, e_c^{r*}, e_2^{r*}) \geq \Pi^b(0, e_{c1}^*, 0; e_1^{r*}, e_c^{r*}, e_2^{r*}) > \Pi^b(e_{c1}^*, 0, 0; e_1^{r*}, e_c^{r*}, e_2^{r*}).$$

The first inequality holds since $\Pi^b(0, \hat{e}_{cc}, 0; e_1^{r*}, e_c^{r*}, e_2^{r*}) = \max_{e_{cc}} \Pi^b(0, e_{cc}, 0; e_1^{r*}, e_c^{r*}, e_2^{r*})$. Let $\Psi = \Pi^b(0, e_{c1}^*, 0; e_1^{r*}, e_c^{r*}, e_2^{r*}) - \Pi^b(e_{c1}^*, 0, 0; e_1^{r*}, e_c^{r*}, e_2^{r*})$. The second inequality holds since

$$\begin{aligned}\Psi =& \frac{2}{9} r(e_1^{r*} - e_c^{r*}) e_{c1}^* \left[1 - r(1 - e_2^{r*})\right] \left[2(\alpha - 2w)d_M - {d_M}^2\right] \\ &+ \frac{1}{9} r(1 - e_1^{r*}) e_{c1}^* \left[1 - r(1 - e_2^{r*})\right] \left[2(\alpha - 2w)d_M + 3{d_M}^2\right] \\ &+ \frac{1}{9} r(e_1^{r*} - e_c^{r*}) e_{c1}^* r(1 - e_2^{r*}) \left[2(\alpha - 2w)d_M + 3{d_M}^2\right] \\ >& 0. \end{aligned}$$

□

# APPENDIX D

# ADDITIONAL RESULTS AND DISCUSSIONS IN CHAPTER 4

## D.1 Parameter values in Plambeck and Taylor (2016) resulting in the profits in the main game in Section 4.3

In this section, we explain the correspondence of our setting and the one in Plambeck and Taylor (2016) and provide one example of values of the parameters in Plambeck and Taylor (2016) which results in the buyer's and supplier's payoffs in our game.

Plambeck and Taylor (2016) consider a simultaneous game between a buyer and a supplier for a given wholesale price $p$,. The supplier chooses a level of responsibility effort $e_r \in (0, 1)$ to improve the socially responsible practice and a level of hiding effort $e_h \in (0, 1)$ to hide the irresponsible practice from the buyer's audit. Meanwhile, the buyer chooses a level of auditing effort $e_a \in (0, 1]$. They find that under a certain condition, as the wholesale price $p$ increases, the supplier's equilibrium responsibility effort decreases and the equilibrium hiding effort increases, resulting in the buyer's expected profit decreases.

To simplify the decision making for the subjects while capturing the key tradeoff of the results, we simplify the wholesale price decisions as a binary decision of the buyer. Meanwhile, by incorporating a low auditing cost, the buyer's equilibrium auditing effort is set as 1 and is not explicitly included in the decision making of the buyer. We also simplify the decisions of the supplier to binary ones between Low Effort and High Effort. The supplier's decision of Low Effort (resp., High Effort) in our setting corresponds to the scenario where the supplier invests in a low (resp., high) responsibility effort and a high (resp., low) hiding effort in Plambeck and Taylor (2016).

Following Plambeck and Taylor (2016), we assume the cost functions for the buyer's auditing effort, the supplier's responsibility effort and hiding effort are: $K_i(e_i) = \frac{c_i}{2} {e_i}^2$ for $i \in a, r, h$. We also note that, given Low Price (denoted by $p_L$), the supplier's High Effort

– high responsibility effort (denoted by $e_r^L$) and low hiding effort (denoted by $e_h^L$) – are the best-response to the buyer's auditing effort (denoted by $e_a^L$); given High Price (denoted by $p_H$), the supplier's Low Effort – low responsibility effort (denoted by $e_r^H$) and high hiding effort (denoted by $e_h^H$) – are the best-response to the buyer's auditing effort (denoted by $e_a^H$). It holds that $e_r^L > e_r^H$. Meanwhile, the buyer's auditing effort $e_a^L$ (resp., $e_a^H$) is the best-response to the supplier's responsibility effort $e_r^L$ (resp., $e_r^H$) and hiding effort $e_h^L$ (resp., $e_h^H$).

One example of the values of the parameters, which make the buyer's and supplier's expected profits in Plambeck and Taylor (2016) equal to the respective profits under each scenario in our game (as depicted in Figure 4.1), is as follows: the low wholesale price, $p_L = 56.025$; the high wholesale price, $p_H = 64.462$; the supplier's high responsibility effort, $e_r^L = 0.550$, and the corresponding hiding effort, $e_h^L = 0.331$; the buyer's auditing effort, $e_a^L = 1$; the supplier's low responsibility effort, $e_r^H = 0.300$, and the corresponding hiding effort, $e_h^H = 0.757$; the buyer's auditing effort, $e_a^H = 1$; the responsibility effort cost parameter, $c_b = 22.399$; the hiding effort cost parameter, $c_h = 24.429$; the auditing effort cost parameter, $c_a = 0.356$; the supplier's production cost, $c = 37.755$; the buyer's value of sourcing from supplier, $v = 90.736$;, the expected damage to buyer if the supplier operates unsafe facility, $d_B = 40.826$; the expected damage to supplier from operating an unsafe facility, $d_S = 0.296$.

### D.2 Supplementary Figures and Tables

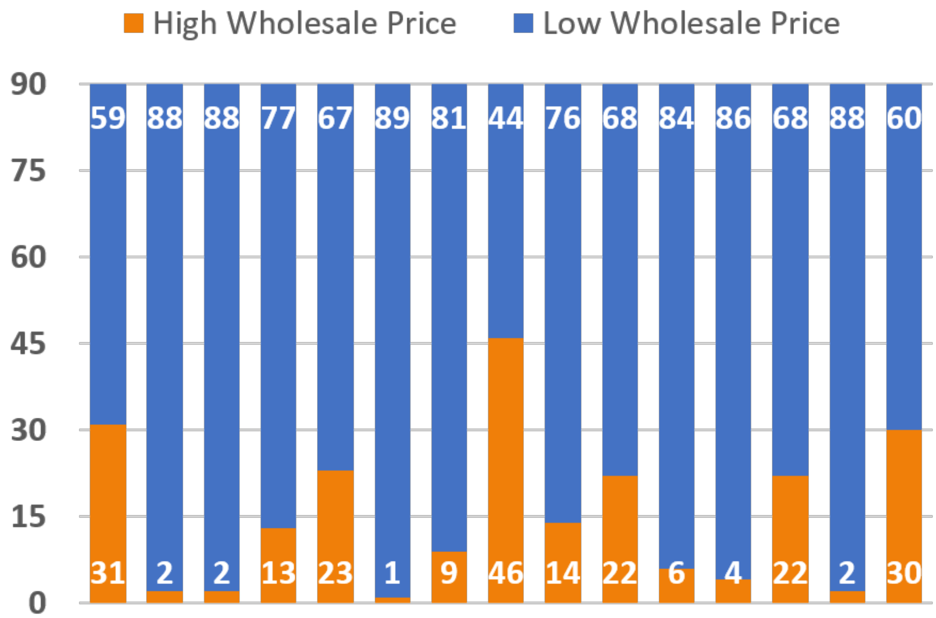


Figure D.1. Buyers' Decisions in Each Cohort in AHB Treatment

Table D.1. Impact of Trust and Round Number on Buyers' Decisions of High Price (NCLP Group in AHB)

| **Coefficients** | **Buyers' Decisions** |
|---|---|
| trust | 0.169** |
| | (0.082) |
| round | 0.001 |
| | (0.020) |
| const | - 2.027*** |
| | (0.391) |

(Logit regression of each buyer's decisions of High Price for each round. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

Table D.2. Impact of Trust, Trustworthiness, Round Number and Observed Proportion of High Price on Suppliers' Decisions of High Effort Given Low Price (NCLP Group in AHB)

| **Coefficients** | **Suppliers' Decisions** | **Suppliers' Decisions** | **Suppliers' Decisions** |
|---|---|---|---|
| trust | - 0.224* | | - 0.295*** |
| | (0.136) | | (0.107) |
| trustworthiness | | - 0.008 | 0.061 |
| | | (0.052) | (0.054) |
| round | - 0.006 | - 0.019 | - 0.008 |
| | (0.018) | (0.012) | (0.019) |
| observed prop. of High Price | - 4.315*** | - 3.565** | - 4.447*** |
| | (1.660) | (1.455) | (1.685) |
| const | 1.377** | 0.694 | 1.091 |
| | (0.652) | (0.516) | (0.942) |

(Logit regression of each supplier's decisions of High Effort given Low Price. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

Table D.3. Impact of Trust, Trustworthiness, Round Number and Observed Proportion of High Price on Suppliers' Decisions of High Effort Given High Price (NCLP Group in AHB)

| **Coefficients** | **Suppliers' Decisions** | **Suppliers' Decisions** | **Suppliers' Decisions** |
|---|---|---|---|
| trust | 0.244 | | 0.231 |
| | (0.163) | | (0.186) |
| trustworthiness | | 0.036 | 0.013 |
| | | (0.042) | (0.050) |
| round | 0.009 | 0.010 | 0.009 |
| | (0.015) | (0.014) | (0.015) |
| observed prop. of High Price | - 0.722 | - 1.101 | - 0.757 |
| | (1.152) | (1.094) | (1.105) |
| const | - 0.656 | 0.037 | - 0.735 |
| | (0.889) | (0.541) | (0.854) |

(Logit regression of each supplier's decisions of High Effort given High Price. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

Table D.4. Impact of Trust, Risk-seeking, and Round Number on Buyers' Decisions of High Price (AHB)

| **Coefficients** | **Buyers' Decisions** | **Buyers' Decisions** |
|---|---|---|
| trust | | 0.193** |
| | | (0.085) |
| risk-seeking | 0.015* | 0.019*** |
| | (0.009) | (0.007) |
| round | - 0.005 | - 0.005 |
| | (0.018) | (0.019) |
| const | - 2.883*** | - 3.909*** |
| | (0.675) | (0.526) |

(Logit regression of each buyer's decisions of High Price. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

Table D.5. Impact of Trust, Risk-seeking, and Round Number on Buyers' Decisions of High Price (NCLP Group in AHB)

| **Coefficients** | **Buyers' Decisions** | **Buyers' Decisions** |
|---|---|---|
| trust | | 0.187** |
| | | (0.088) |
| risk-seeking | 0.015 | 0.019** |
| | (0.010) | (0.008) |
| round | 0.001 | 0.002 |
| | (0.019) | (0.020) |
| const | - 2.242*** | - 3.298*** |
| | (0.757) | (0.566) |

(Logit regression of each buyer's decisions of High Price. Cohorts' random effects. Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.)

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Jiayu Chen was born in the city of Dalian, China. After completing high school, she moved to the U.S. to pursue a BS degree with dual major in Mathematics and Graphic Design from Syracuse University. Subsequently, she received an MS degree in Applied Mathematics from the University of Illinois at Urbana-Champaign. She joined the PhD program in Management Science at the Naveen Jindal School of Management, The University of Texas at Dallas (UTD) in 2014. Her primary research interests focus on sustainable and socially responsible operations management in procurement and retail. Her recent work is forthcoming in *Manufacturing & Service Operations Management*. Her work has also been recognized by the POMS College of Sustainable Operations in the 2019 Best Student Paper Competition. She was nominated for the Best Student Teacher Award at UTD for her teaching in Spring 2018.

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