6-2022

Responsible Sourcing and Supply Chain Traceability

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Abstract

This paper explores a buyer's tracing and its supplier's own sourcing decisions in a multi-tier supply chain. We explore what different stakeholders can do to achieve a more transparent and/or responsible supply chain. We establish that under rather general conditions, the two firms will adopt mixed strategies in equilibrium, a focal case of our analysis. The mixed-strategy results first explain at the micro level why many companies are not certain about whether their supply chains are ethical or not. At the more macro level, they also help explain why a significant proportion of the buyers did not trace or comply with transparency regulations. We then show that more responsible sourcing can be induced by lowering the buyer's tracing cost but not by reducing the supplier's own responsible sourcing cost. We also find that more transparency does not always imply more responsible sourcing. For the external stakeholders, more responsible sourcing may be obtained through lowering tracing costs, improving tracing or public discovery of violations, and imposing more significant reputational damage or penalties only on the buyer. For the internal stakeholders, a contract incorporating both responsible sourcing cost sharing and non-compliance penalty if found may be constructed for the first-best supply chain efficiency and likely social optimality under some simple sufficient conditions.

Keywords: responsible sourcing, compliance, traceability, visibility, transparency, game theory

1. Introduction

> *The Nike product has become synonymous with slave wages, forced overtime and arbitrary abuse. I truly believe that the American consumer does not want to buy products made in abusive conditions.* – Philip H. Knight, Chairman and Chief Executive, Nike (May 13, 1998)

In the 1990s, a series of publicized issues and protests forced Nike to acknowledge its labor problems and be more transparent about its supply chain. In 2005, it became the first major retailer to disclose the names and locations of its factories (Banjo, 2014). More companies are now tracing the provenance of their supply chains these days to assure responsible sourcing because of pressure from governments, consumers, nongovernmental organizations (NGOs), investors and other external stakeholders (Bateman and Bonanni, 2019). However, according to a recent chief procurement officer survey (Deloitte, 2020), only half reported high visibility into their first-tier suppliers while 90% responded with moderate to very low visibility beyond the first tier of their extended supply network. Companies find that tracing is not only costly but also does not provide clear benefits (Sodhi and Tang, 2019). Costs and complexity are the top two traceability barriers for sustainable operations (Garcia-Torres *et al.*, 2019).

Since the terminology is not yet standard, Sodhi and Tang (2019) define *traceability* as the capability of a company to ascertain provenance, *visibility* as the efforts to learn more about its operations both upstream and downstream in the supply chain, and *transparency* as the disclosure of information to the public about its upstream operations and products. The International Organization for Standardization (ISO) gives a more comprehensive definition of traceability: *ability to trace the history, application or location of an object* (International Organization for Standardization, 2015). By either definition, traceability is one key aspect of supply chain transparency for sustainability (Naden, 2017; Sodhi and Tang, 2019). It helps identify social and environmental issues and risks in the supply chain, holds stakeholders accountable, and is a starting point for improvement (McKinsey, 2019). With poor supply chain traceability, companies may risk having reputational damages caused by the public discovery of unethical supplier practices or undesirable supply provenance. Notable examples include many different social and environmental crises affecting prominent firms in two exemplary industries that underline the relevance of supply chain traceability.

First, in the apparel industry, the catastrophic 2012 Tazreen factory fire and the 2013 Rana Plaza building collapse in Bangladesh revealed serious safety concerns in subcontracting factories for top brands like Hennes & Mauritz, Benetton, and Wal-Mart (Al-Mahmood *et al.*, 2013). Wal-Mart claimed then that months before the fire, Tazreen was removed from their list of authorized factories and a supplier's use of Tazreen violated its rules (Al-Mahmood *et al.*, 2012). However, in 2019, the Wall Street Journal traced and found that the top three US apparel retailers (Wal-Mart, Amazon, and Target) still sold clothes from unsafe factories, blacklisted by safety-monitoring groups.

Second, in the computers and electronics industry, human-rights abuses, like slavery and child labor, are serious problems to many companies (International Labour Organization, 2017). In 2016, there were 5.4 victims of modern slavery for every thousand people in the world (Gammarano, 2019). It was estimated that in 2014, 1,262 US public companies shelled out roughly $709 million and six million staff hours to reveal whether their supply chains contain (conflict) minerals linked to violence in Africa. Moreover, 90% of the companies reported that whether their products are conflict-free remains undetermined, and two-thirds (including Google and Amazon) did not describe the country of origin of their metals as required (Chasan, 2015).

Over the past decade, many new laws pertaining to transparency were passed because of the above-mentioned fallouts among others (Bateman and Bonanni, 2019). There are Section 54 of UK Modern Slavery Act (2015) and The California Transparency in Supply Chains Act (2012) for combating forced labor, US Food Safety Modernization Act (FSMA) for ensuring food safety (US Food & Drug Administration, 2011), and Section 1502 of the Dodd-Frank Act for policing conflict minerals (US Security and Exchange Commission, 2017) with more coming in other different countries (Sorge and Boston, 2021). Though the regulations may help bring awareness of the issues to public attention, many companies and industries haven't fully complied with them. For instance, studies on the Modern Slavery Act shows that overall business response has been rather disappointing as half of the statements are symbolic (cosmetic) instead of substantive, that is, no meaningful information on whether the actions taken were effective (Monciardini *et al.* 2021 and references within). Due to the lack of injunction or administrative penalty for failing to report, only 60% of companies complied under the law over the past six years (Business and Human Rights Resource Centre, 2021). Similarly, for the conflict minerals, only 58% of the companies subject to SEC's disclosure rule were able to determine the country of origin (US Government Accountability Office, 2021). Like the Modern Slavery Act and other due diligence legislation, there are also no financial or criminal penalties but rather just the possibilities of being named for companies not complying with the Dodd-Frank Act (Woody, 2019; Gallagher and Piwowar, 2014). There could be, however, high reputational costs if any severe violations are brought to the public attention as in the landmark legal case where Apple, Alphabet, Microsoft, Dell, and Tesla were named over Congolese child mining deaths (Toh, 2019).

These examples raise the question of what different stakeholders can do to achieve a more transparent and/or responsible supply chain. Specifically, what can the external stakeholders, like government agencies, NGOs, and investors, do to force a supply chain to be more responsible? And how can the two internal stakeholders, the buyer and its supplier, do and collaborate for more responsible sourcing? To answer these questions, we develop a game-theoretic model to study the strategic interactions between two firms, a buyer and its direct supplier, in a long multi-tier supply chain concerning tracing and responsible sourcing. A buyer may *trace* or *not trace* its supplier's own sourcing, which can be either *responsible* or *unethical*. Each firm's profit is not only affected by its own decision but also the other's.

One key modeling feature of our paper is that we explicitly model whether a company complies with a transparency regulation (e.g., the Modern Slavery Act), not merely how much effort the company voluntarily exerts, which may be subjective and ill-defined. Another feature is that unlike previous works mostly assume immediate separation from the non-compliant supplier and both parties make zero profit, we allow the at-risk supplier to take corrective actions at a cost to become responsible, a practice recommended by most guidelines for supply chain transparency regulations (Harris, 2015; UK Home Office, 2020; OECD, 2016) and implemented by many companies (Carrefour, 2021; Home Depot, 2021; ALDI, 2020).

We establish that under rather general conditions, the two firms will adopt mixed strategies in equilibrium, which helps explain: 1) at the micro level, why many companies are uncertain about whether their supply chains are ethical or not (Al-Mahmood *et al.*, 2012; Chasan, 2015), and 2) at the macro level, why a significant proportion of the buyers did not trace or comply with the regulations (Business and Human Rights Resource Centre, 2021; US Government Accountability Office, 2021). Next, contrary to intuition, we find that neither the responsible sourcing cost nor correction cost affects the supplier's tendency to source responsibly. However, lowering tracing costs like joint audits or third-party certification may increase such tendency while the buyer's tracing likelihood remains unchanged. Moreover, we show that raising the effectiveness of tracing and public discovery has opposite effects on the two firms' decisions: the buyer traces less while the supplier source more responsibly. The external stakeholders must know that more transparency does not imply more responsible sourcing. The effective external instruments for more responsible supply chains are lowering tracing costs, improving private or public discovery of violations, and imposing more significant reputational damage or penalties only on the buyer. Lastly, for the two internal stakeholders, a cost-sharing and penalty contract may be used to coordinate the supply chain and achieve the centralized profit, which can also be socially optimal when the potential reputational damage to the buyer is high.

Our paper is related to previous research on supply chain transparency and regulatory compliance. The literature on transparency is an emerging research stream expanding quickly in recent years and spans several disciplines (Montecchi *et al.*, 2021). For a discussion of various transparency-related concepts and contextual applications, see Garcia-Torres *et al.* (2019) for traceability for sustainability in apparel supply chains, Corallo *et al.* (2020) for the relationship between traceability and product lifecycle, Kamble *et al.* (2020) and Kouhizadeh *et al.* (2021) for emerging technologies like blockchain and Internet-of-Things, and Sauer and Seuring (2019) and Jabbour *et al.* (2019) for multi-tier sustainable supply chain management. Sodhi and Tang (2019) define supply chain traceability as the capability of a company to ascertain provenance, supply chain transparency as the supply chain information disclosed to the public. They present potential benefits and risks of offering transparency to external stakeholders, and propose topics for research on supply chain transparency.

Most of the modeling works on supplier non-compliance with buyer's code of conduct largely focuses on inspections and audits (Dawande and Qi, 2020). Plambeck and Taylor (2016) is the first in the supply chain literature to model a supplier's effort to hide problems from a buyer. They identify conditions under which the buyer's audit effort may backfire, that is, motivate the supplier to comply less and deceive more. Caro *et al.* (2018) show two buyers sharing a common supplier can improve their supplier's compliance through joint and shared audits with a collective penalty, as compared to the independent audit-penalty mechanism. Fang and Cho (2020) further extend Caro *et al.* (2018) by explicitly considering both positive and negative externalities of social responsibility violations among multiple buyers, who may cooperate using joint or shared audits on a common supplier. Chen *et al.* (2019) study whether a buyer should reveal its relationship with a supplier and how that affects NGO monitoring supply chain sustainability.

Although related, this paper differs from the studies of supply chain transparency in two distinct ways as mentioned previously. First, all works above assume arbitrary effort levels for the buyer's tracing or the supplier's sourcing decisions (the more, the better) while we only allow binary choices (whether met or not the requirements) as defined by the regulation of interest, like Section 1502 of Dodd-Frank Act and Section 52 of UK Modern Slavery Act

(Global Witness, 2015; Business and Human Rights Resource Centre, 2021). Second, unlike most earlier works assume immediate separation from the non-compliant supplier and both parties make zero profit, we allow the at-risk supplier to take corrective actions at a cost to be compliant, a practice recommended by many guides for supply chain transparency (Harris, 2015; UK Home Office, 2020; OECD, 2016).

The remainder of this paper is organized as follows. Section 2 describe the model developed. We analyze it and present the main results in section 3. Section 4 discusses the results and presents our conclusions, and suggestions for future work on this topic.

2. The Model

In a multi-tier supply chain, consider a buyer B buying a product worth p from its direct supplier S for a wholesale price w and thus B has a base margin of $p - w$. To make the product, supplier S may further source its own parts and raw materials. c is the baseline cost of production and unknown/risky sourcing, which may be a violation of the buyer's code of conduct if traced with probability α or even a violation of some regulation discoverable by the public with probability β. For ease of exposition, this type of risky sourcing is called *unethical* in contrast to the alternative *responsible* sourcing at an additional cost c_R but with zero probability of any responsibility violation. Without loss of generality, the demand is normalized to 1 as in Plambeck and Taylor (2016) and Caro *et al.* (2018). While the above assumptions regarding each party's basic revenue and cost structure are similar to those, our model is unique in two ways in the context of regulatory compliance in supply chain transparency: 1) what tracing effort level B may choose and what responsible sourcing effort level S may choose, and 2) what happens when S's unethical sourcing practice is found by B but not revealed to the public yet.

First, since we focus on whether S sources responsibly as clearly defined and required by the regulation (an either-or binary decision, like sourcing conflict-free or not), we assume that S would incur an additional cost of c_R for responsible sourcing. Previous works mainly study emerging and voluntary responsible sourcing practices where penalties of unethical sourcing are linear in arbitrary effort levels (Plambeck and Taylor, 2016; Caro *et al.*, 2018). It can be subjective to claim that an effort level is 31.75% since the maximum (risk-free) level is not defined without a regulation (e.g., does fair labor consider only fair wage or other social responsibilities, like safety, too?). To this end, our paper focuses on existing and mandatory responsible sourcing regulations where the compliance requirements are clearly defined (either met or not, like conflict-free or not), and thus agencies (governments and NGOs) can monitor and report the compliance rates accordingly. For instance, Business and Human Rights Resource Centre (2021) reports "40% company non-compliance over the past six years" and US Government Accountability Office (2021) reports "an estimated 58 percent of companies reported preliminary determinations regarding the source of their conflict minerals." Given no advantage for a lower degree of compliance unless otherwise mentioned in the regulation, it is straightforward to show that companies' best responses are to exert either no effort at all or the exact effort for full compliance. Likewise, whether B traces and discloses relevant supply chain information is also a binary decision as defined by whether it meets all the minimum regulatory requirements (Global Witness, 2015; Business and Human Rights Resource Centre, 2021).

Second, to better know S's sourcing practice and thus the origin of its product, B may conduct due diligence to trace its supply chain at cost c_T like those demanded by the SEC (US Security and Exchange Commission, 2017) and European Commission (European Commission, 2020). Such diligence allows B to uncover any unethical sourcing by S with probability α and may demand corrective actions on S in the case of any found violations of its code of conduct. In the event of a violation, early works like Plambeck and Taylor (2016) and Lu and Tomlin (2021) assume, B always drops S and thus both earn zero with no alternatives. In contrast, our model particularly considers the suggestion by many guidelines for transparent supply chain regulations to allow S to rectify any violations if found (Harris, 2015; UK Home Office, 2020; OECD, 2016). VF Corporation, for example, expects their at-risk (developmental) suppliers to remediate all issues noted in the corrective action plan and only terminate their relationship with those factories having persistent problems and no remediation (VF Corporation, 2021). The correction will cost S not only c_R for responsible sourcing but also an additional cost c_r, such as increased costs resulting from changing its own suppliers in an expedited fashion (Guo *et al.*, 2016). If, however, with the complementary probability $1 - \alpha$ such diligence fails to discover the violations or B simply decides not to trace, the unethical sourcing may be discovered by NGOs and revealed to the public at probability β. The revelation of such wrongdoing will cost B reputational damage of d_B and S damage of d_S. Thus, the profit of each firm is affected by whether S sources responsibly (c_R), by whether B traces (c_T), by the probability α that B finds any violations if tracing, by the public discovery (with the probability β), by S's cost of corrective actions (c_r), and lastly by potential damage to B (d_B) and S (d_S), respectively.

We use the following notation (equations (1) - (16)) to denote the profit functions of the two firms, where the superscript pairs indicate whether buyer B Traces or does Not trace its supply and whether supplier S sources Responsibly or Unethically:

$$\pi_B^{TR} = p - w - c_T \tag{1}$$

$$\pi_S^{TR} = w - c - c_R \tag{2}$$

$$\pi_B^{TU} = \alpha(p - w) + (1 - \alpha)(p - w - \beta d_B) - c_T \tag{3}$$

$$\pi_S^{TU} = \alpha(w - c - c_R - c_r) + (1 - \alpha)(w - c - \beta d_S) \tag{4}$$

$$\pi_B^{NR} = p - w \tag{5}$$

$$\pi_S^{NR} = w - c - c_R \tag{6}$$

$$\pi_B^{NU} = p - w - \beta d_B \tag{7}$$

$$\pi_S^{NU} = w - c - \beta d_S \tag{8}$$

π_B^{TR} in (1) and π_S^{TR} in (2) denote the profits realized by B and S, respectively, when B traces at cost c_T and S sources responsibly at cost c_R. The expressions π_B^{TU} (3) and π_S^{TU} (4) characterize the profits when B traces and S sources unethically. In this case, B incurs the tracing cost c_T but is able to find and correct S's unethical sourcing with probability α so its margin is not affected. However, there is a complementary probability of $1 - \alpha$ that B fails to find such violations and incurs the damage cost d_B if the violations are revealed to the public with probability β. Similarly, when sourcing unethically, S, if caught by B with probability $1 - \alpha$, incurs the costs of responsible sourcing plus corrective actions $c_R + c_r$. If not caught by B but later discovered by the public with probability β, S's unethical sourcing will then lead to damage of d_S. Equations (13)-(16) are derived in an analogous manner. The strategy space and consequent expected profits of the game between the two firms are summarized in Table 1.

3. Analysis

The Nash equilibria of the game under normal-form representation can be characterized by evaluating each firm's best response to the other firm's strategy. The first two propo-

		Supplier S	
		Responsible	Unethical
Buyer B	Trace	π_B^{TR}, π_S^{TR}	π_B^{TU}, π_S^{TU}
	Not trace	π_B^{NR}, π_S^{NR}	π_B^{NU}, π_S^{NU}

Table 1: Responsible sourcing and tracing game

sitions characterize the dependence of the Nash equilibria on the parameters of the model. Proposition 1 focuses on the tracing and responsible sourcing costs.

Proposition 1. *For $c_T > 0$, $\bar{c}_T = \alpha\beta d_B$, $\bar{c}_R = \beta d_S$, and $\bar{\bar{c}}_R = \beta d_S + \left(\frac{\alpha}{1-\alpha}\right) c_r$:*

a. *When $c_R < \bar{c}_R$, NR is the unique equilibrium.*

b. *When $c_T > \bar{c}_T$ and $c_R > \bar{c}_R$, NU is the unique equilibrium.*

c. *When $c_T < \bar{c}_T$ and $c_R > \bar{\bar{c}}_R$, TU is the unique equilibrium.*

d. *When $c_T < \bar{c}_T$ and $\bar{c}_R < c_R < \bar{\bar{c}}_R$, there exists no pure-strategy equilibrium but an unique mixed-strategy (MS) equilibrium:*

Buyer B traces with probability $\mathrm{Pr}^T = \frac{c_R-\beta d_S}{\alpha(c_R+c_r-\beta d_S)}$ and expected profit

$$\pi_B^{MS} = p - w - \frac{c_T}{\alpha} \tag{9}$$

Supplier S sources responsibly with probability $\mathrm{Pr}^R = 1 - \frac{c_T}{\alpha\beta d_B}$ and expected profit

$$\pi_S^{MS} = w - c - c_R \tag{10}$$

All proofs can be found in the Appendix.

Each of the three thresholds ($\bar{c}_T$, $\bar{c}_R$, and $\bar{\bar{c}}_R$) specifies a value of the corresponding cost when one firm's best response changes given the other firm's strategy. For example, using the profit functions (1)-(16), it is straightforward to show that $\pi_B^{TU} > \pi_B^{NU}$ if and only if (iff) $c_T < \bar{c}_T$, and so even though S may source unethically, B will only trace when its tracing cost is sufficiently low. However, as long as S sources responsibly, B will always choose not to trace regardless of the tracing cost. As for S's best responses, if B does not trace, then S will source responsibly iff $c_R < \bar{c}_R$ (derived from $\pi_S^{NR} > \pi_S^{NU}$), and if B traces, S will source responsibly iff $c_R < \bar{\bar{c}}_R$ (derived from $\pi_S^{TR} > \pi_S^{TU}$). Since $\bar{\bar{c}}_R > \bar{c}_R$ for any corrective cost $c_r > 0$, S is willing to pay more for responsible sourcing (up to $\bar{\bar{c}}_R - \bar{c}_R = \left(\frac{\alpha}{1-\alpha}\right) c_r$) when B traces, than when B does not. Therefore, for B to better induce S to source responsibly (higher $\bar{\bar{c}}_R$) through tracing, it is important to ensure tracing is effective (α) or the additional corrective cost is high (c_r).

Figure 1 provides graphical illustrations based on a numerical example ($p = 2$, $w = 1$, $c = 0.2$, $c_r = 0.07$, $\alpha = 0.8$, $\beta = 0.4$, $d_B = 0.9$, and $d_S = 0.2$). In our discussion of these and subsequent figures, a "region" is defined as an area in which a particular Nash equilibrium (such as, TR, Mixed Strategies, NU, etc.) occurs. An interpretation of the different regions in these figures is as follows.

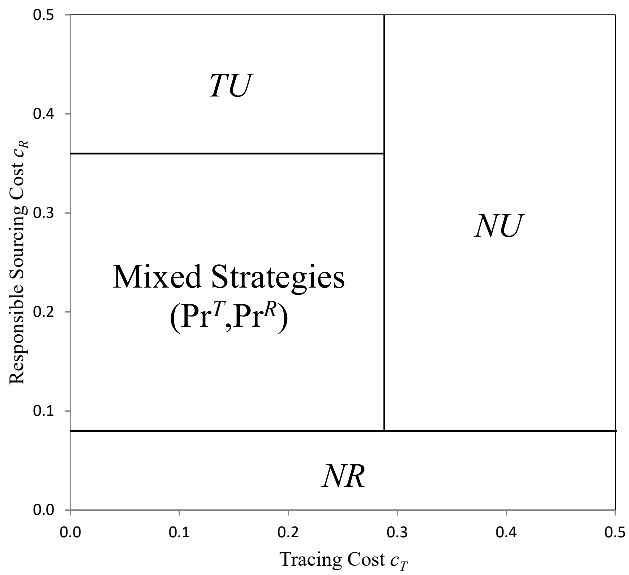


Figure 1: Equilibrium regions in tracing and responsible sourcing costs

When c_R is low enough ($< \bar{c}_R$), the benefit of responsible sourcing for S always outweighs the cost so S sources responsibly regardless of whether B traces or not (that is, R is the dominant strategy for S), while B always prefers no tracing as long as S is responsible. In this case, the benefit of sourcing ethically for S is exactly the expected damage (βd_S) avoided. Hence, NR is the equilibrium when S's expected damage is high or equivalently high public discovery probability β or high damage d_S.

Conversely, when c_R is high ($> \bar{c}_R$), then whether the benefit is sufficient to recoup the cost for S first depends on B's strategy. In particular, when the tracing cost is high enough ($c_T > \bar{c}_T$), B is better off not tracing since the cost is greater than the (expected) benefit, $\alpha\beta d_B$. Knowing B not tracing its sourcing and the high cost for responsible sourcing, S then sources unethically. Hence, NU is the equilibrium when the expected damages to both B and S are low (relative to the tracing and responsible sourcing costs), or equivalently, low probability of effective tracing (α), low probability of public discovery (β), or low realized damages (d_B and d_S).

If c_T, however, is low ($< \bar{c}_T$), then B is now incentivized to conduct due diligence and trace S's sourcing. When facing B's tracing, S's best response then depends on exactly how high its responsible sourcing cost may be. If responsible sourcing is very costly ($c_R > \bar{\bar{c}}_R$), S is better off with unethical sourcing in response to B's tracing, and thus TU is the equilibrium.

For intermediate cost ($\bar{c}_R < c_R < \bar{\bar{c}}_R$), however, there exists no pure-strategy equilibrium. This is a more common case since the others take more extreme values, very low or high, leading to the above pure-strategy equilibria. In this case, one firm is always better off deviating from any possible pure strategies. Thus, B and S must play mixed strategies in equilibrium. For B to be indifferent between tracing and not tracing, the cost of tracing (c_T) must equal the expected damage savings ($(1-\Pr^R)\alpha\beta d_B$). Similarly, S must also randomize and thus be indifferent between sourcing responsibly and unethically, that is, the cost of responsible sourcing (c_R) must be the same as the expected corrective actions and damage savings ($\Pr^T \alpha(c_R+c_r)+(1-\Pr^T \alpha)\beta d_S$). Hence, in this case, both B and S will adopt mixed strategies in equilibrium with the probabilities and profits as characterized in Proposition 1(d). The mixed-strategy equilibrium can be directly interpreted as each firm randomizes between its two pure strategies or one firm's uncertainty about what the other firm will do (Fudenberg and Tirole, 1991; Gibbons, 1992). This helps explain why many companies are uncertain about whether their supply chains are ethical or not (that is, $\Pr^R$ is neither 1 nor 0) in this more common case of intermediate responsible sourcing cost. As seen in the Wal-Mart subcontracting and the conflict minerals tracing cases (Al-Mahmood *et al.*, 2012; Chasan, 2015), companies are not certain about whether their suppliers source responsibly.

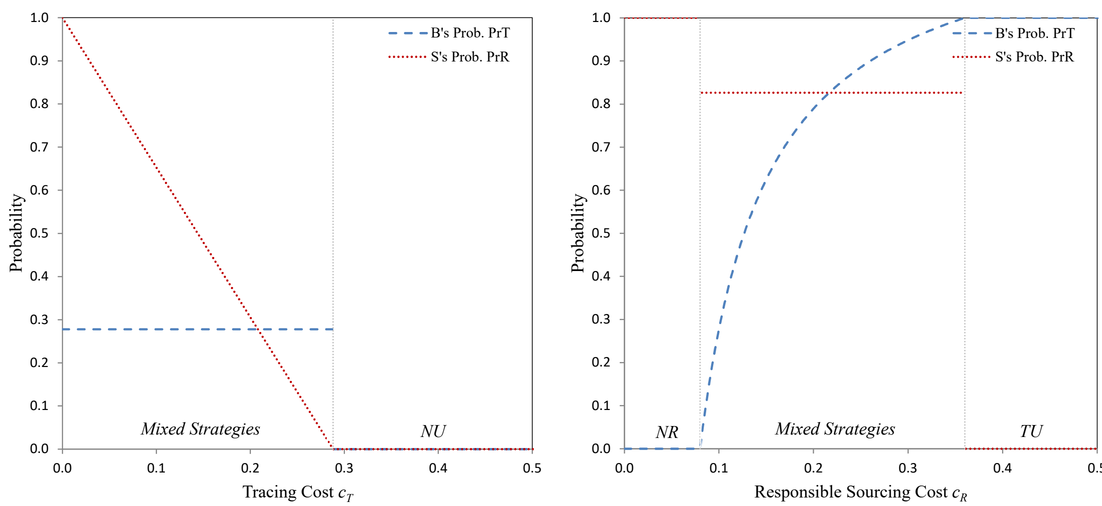
Alternatively, for a large population of buyers and suppliers, a mixed strategy can also be viewed as describing a situation in which different fractions of the population play different pure strategies (Fudenberg and Tirole, 1991). Since the number of players involved in most regulatory compliance is high, the latter interpretation also helps glean insights for government agencies and nongovernmental organizations (NGOs) concerning unethical sourcing practices. This helps explain why as observed in US Government Accountability Office (2021) and Business and Human Rights Resource Centre (2021), a great proportion of the buyers do not trace and comply with the regulations ($\Pr^T$, interpreted as a fraction, is between 0 and 1). The following corollary sheds light on what and how different factors affect the dynamics of the mix-strategy equilibrium.

Corollary 1. *For the mixed-strategy (MS) equilibrium,*

a. $\Pr^T$ *is increasing in* c_R *and decreasing in* c_r, d_S, α, *and* β.

b. $\Pr^R$ *is decreasing in* c_T *and increasing in* d_B, α, *and* β.

Corollary 1(a) and (b) depicts how the probabilities (or fractions) of tracing and responsible sourcing ($\Pr^T$ and $\Pr^R$) may respond to changes in different factors. It is rather surprising at first sight that B's probability of tracing ($\Pr^T$) is not directly affected by B's own cost of tracing (c_T) but instead increased by S's cost of responsible sourcing (c_R). According to Corollary 1(b), to induce more responsible sourcing, the buyer may lower its tracing cost by joint audits or third-party certification, e.g., the Alliance for Bangladesh Work Safety in the apparel industry and Responsible Minerals Assurance Program by Responsible Minerals Initiative (RMI) in the electronics industry. Such behaviors can be seen in Figures 2(a) and 2(b) where in the relevant mixed-strategy regions with $c_R = 0.1$ and $c_T = 0.05$, respectively. The dash lines representing the tracing probability ($\Pr^T$) remain constant in the tracing cost



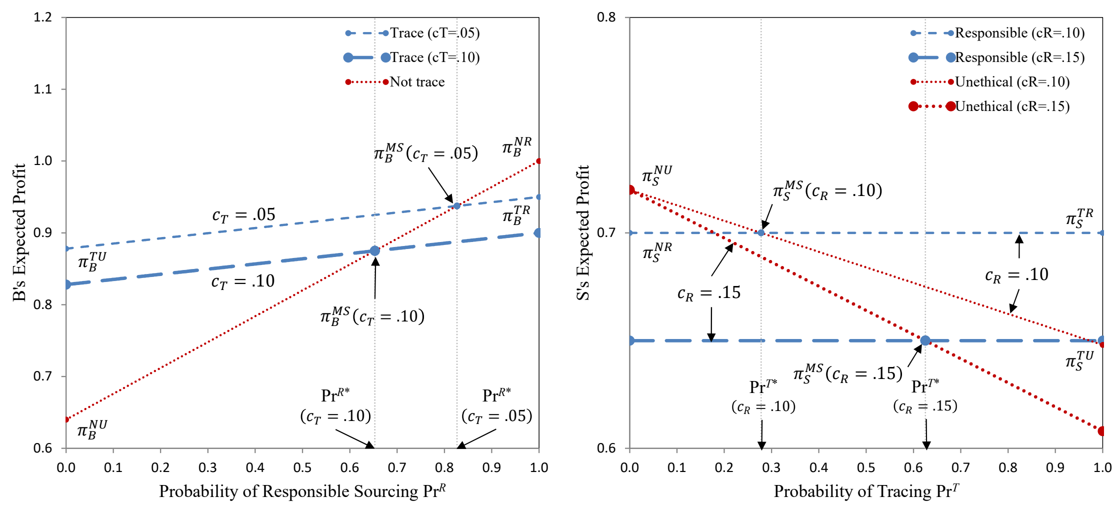
(a) Tracing cost (b) Responsible sourcing cost

Figure 2: Sensitivity of mixed-strategy probabilities to tracing and responsible sourcing costs

(c_T) but increase in the responsible sourcing cost (c_R), while the dotted lines representing the probability of responsible sourcing ($\Pr^R$) decrease in c_T but stay constant in c_R. The reason is that what is best for one firm depends not only on what it does but also on what the other firm does. When B tends to trace less due to the higher tracing cost (the direct effect), S takes advantage of such inclination and sources less responsibly because of the lower chance being caught, which in turn incentivizes B to trace more (the strategic effect). These two effects offset each other for B and thus no change in the probability or fraction of buyers tracing ($\Pr^T$) but make S less responsible (lower $\Pr^R$). This can also be readily seen from how the equilibrium probabilities are determined. Recall that in the MS equilibrium, the cost of tracing must be the same as the expected damage savings:

$$c_T = (1 - \Pr^R)\alpha\beta d_B \tag{11}$$

All else equal, tracing at a higher cost (c_T) is only justifiable if the risk of S not sourcing responsibly is higher ($1 - \Pr^R$) for B to be indifferent between tracing and not tracing. As seen in Figure 3(a), $\Pr^R$ decreases from 0.83 to 0.65 when c_T increases from 0.05 (dash line) to 0.10 (thick long dash line).



(a) Buyer's Expected Profit (b) Supplier's Expected Profit

Figure 3: Expected profits in mixed-strategy equilibrium to probabilities of responsible sourcing and tracing

Similarly, it requires a higher tracing probability ($\Pr^T$) from B to justify a higher responsible sourcing cost (c_R) for S to be indifferent between responsible and unethical sourcing:

$$c_R = \Pr^T\alpha(c_R + c_r) + (1 - \Pr^T\alpha)\beta d_S \tag{12}$$

The effects of other factors on the two probabilities can be explained using similar arguments. Figure 3(b) illustrates that $\Pr^T$ raises from 0.28 to 0.63 when c_R increases from 0.10 to 0.15.

It is, however, worth noting that first, the costs of responsible sourcing (c_R) and corrective actions (c_r) have the opposite effects on the tracing probability ($\Pr^T$), and second, the probabilities of effective tracing (α) and public discovery (β) are the only two factors that affect both tracing and responsible sourcing probabilities but again in the opposite directions.

Equation (12) and Figure 3(b) explain why a higher responsible sourcing cost (c_R) for S leads to a higher tracing probability ($\Pr^T$) for B. On the other hand, a higher cost for corrective actions (c_r) makes S more likely to source responsibly, which B may take advantage of and lower its tracing probability ($\Pr^T$). Therefore, B would have to increase its tracing rate ($\Pr^T$) or otherwise S is more likely to source unethically facing a higher responsible sourcing cost (c_R) or a lower cost for corrective actions (c_r). Note that neither costs (c_R or c_r) really affect S's sourcing strategy ($\Pr^R$) as the direct influences are fully offset by B's strategic adjustments in its tracing probability ($\Pr^T$) to keep S from favoring one choice over the other.

Next, the higher the rates of discovery (either α or β), the lower B's probability of tracing ($\Pr^T$) or the greater S's probability of responsible sourcing ($\Pr^R$). That is, an outcome of more tracing does not imply more responsible sourcing. Since raising the two discovery probabilities has the opposite effects on B's tracing and S's responsible sourcing, governments and NGOs need to know what they are after depending on their goals and missions. For instance, supply chains may be made more responsible through lowering tracing costs, improving private or public discovery of violations, and imposing more significant reputational damage or penalties only on the buyer.

Proposition 2. *When $c_T < \bar{c}_T$ and $\bar{c}_R < c_R < \bar{\bar{c}}_R$,*

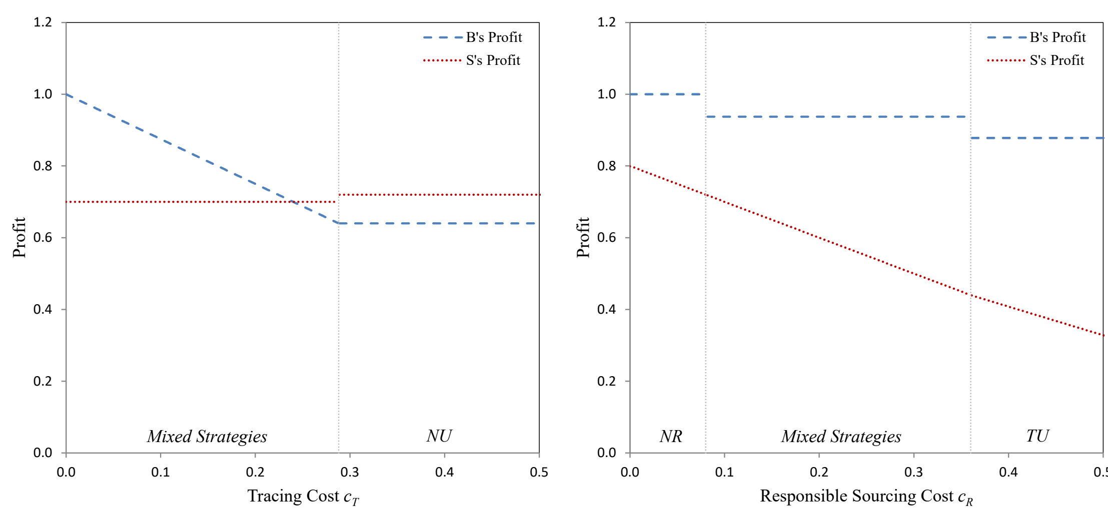
a. $\pi_B^{NR} > \pi_B^{TR} > \pi_B^{MS} > \pi_B^{TU} > \pi_B^{NU}$
b. $\pi_S^{NU} > \pi_S^{NR} = \pi_S^{MS} = \pi_S^{TR} > \pi_S^{TU}$

Proposition 2(a) and (b) rank both B's and S's profits in the MS equilibrium against those in the pure strategies. It is not that surprising that the expected profits of both firms rank in the middle among all strategies as seen in Figures 3(a) and 3(b). Recall that each firm's MS profit and the corresponding strategy mixture of the other firm are determined by the interception of its two pure-strategy profit lines because of its indifference between the two strategies. Therefore, the MS profits are simply convex combinations (or weighted averages) of the pure-strategy profits. However, carefully examining the two rankings suggests that NR may be a (weakly) better outcome for both firms if the two firms can cooperate since $\pi_B^{NR} > \pi_B^{MS}$ and $\pi_S^{NR} = \pi_S^{MS}$. In fact, NR is a strictly better outcome for the two combined since $\pi_B^{NR} + \pi_S^{NR} > \pi_B^{MS} + \pi_S^{MS}$, which presents an incentive for a coordinated supply chain and a better societal outcome, that is, achieving responsible sourcing without incurring tracing cost. We will explore this possibility further at the end of our analysis.

Corollary 2. a. π_B^{MS} *is increasing in* p *and* α *and decreasing in* w *and* c_T*.*
b. π_S^{MS} *is increasing in* w *and decreasing in* c *and* c_R*.*

Corollary 2(a) and (b) depicts how the (expected) profits of the two firms (π_B^{MS} and π_S^{MS}) may respond to changes in different factors. It is interesting to note that in the MS equilibrium, S's expected payoff is identical to those in the responsible sourcing equilibria (i.e., NR and TR as seen in Figure 3(b)) while for B, the expected payoff is its gross margin $(p - w)$ minus a scaled tracing cost $(\frac{c_T}{\alpha})$. The scaling may be interpreted as an extra cost beyond normal tracing cost (c_T) to make up for any ineffectiveness of tracing ($\alpha < 1$). Such tracing inefficiency will be non-existent in the case of a coordinated supply chain discussed later.

Now that we understand how each firm's MS profits are determined, what are the effects of different factors on profit? Figures 4(a) and 4(b) show what happens to profits for each firm as the tracing and responsible sourcing costs vary (the two focal factors in Proposition 1 and Figure 1). In the example depicted in Figure 4(a), with c_R set at 0.1, both profit curves



(a) Tracing cost (b) Responsible sourcing cost

Figure 4: Sensitivity of profit to tracing and responsible sourcing costs

are monotone and piecewise continuous but move in opposite directions as c_T increases. That is, B's profit falls as its tracing cost rises (in the MS region), then levels off when it does not trace. On the other hand, at the tracing cost threshold $\bar{c}_T = 0.29$, S's profit jumps from one constant level $(w - c - c_R)$ in the MS region to another $(w - c)$ in the NU region, benefiting from B's not tracing its (unethical) sourcing. In Figure 4(b) (with $c_T = 0.05$), as c_R rises, it moves from responsible sourcing (in the NR region) through mixed sourcing, and then unethical sourcing (TU). Note that in the last TU region, c_R may still affect S's profit as B traces and may find S's unethical sourcing, resulting in an expected cost $\alpha(c_R + c_r)$ for S. B's profit drops at the thresholds, $\bar{c}_R = 0.08$ and $\bar{\bar{c}}_R = 0.36$, when S behaves less responsibly (from responsible to MS, and then from MS to unethical).

Having examined the effects of the costs and the MS equilibrium, we next look more closely at the two exogenous probabilistic factors (α and β).

Proposition 3. *For* $\bar{\beta} = \frac{c_R}{d_S}$, $\bar{\bar{\beta}} = \frac{c_T}{\alpha d_B}$, *and* $\bar{\bar{\bar{\beta}}} = \frac{c_R}{d_S} - \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{c_r}{d_S}\right)$*:*

a. *When* $\beta > \bar{\beta}$*,* NR *is the unique equilibrium.*

b. *When* $\beta < \min\{\bar{\beta}, \bar{\bar{\beta}}\}$*,* NU *is the unique equilibrium.*

c. *When* $\bar{\bar{\beta}} < \beta < \bar{\bar{\bar{\beta}}}$*,* TU *is the unique equilibrium.*

d. *When* $\max\{\bar{\bar{\beta}}, \bar{\bar{\bar{\beta}}}\} < \beta < \bar{\beta}$*, there exists no pure-strategy equilibrium but an unique mixed-strategy equilibrium: B traces with probability* Pr^T *and S sources responsibly with probability* Pr^R*.*

Proposition 3 characterizes the game, providing some α-dependent thresholds for the probability of public discovery (β) that uniquely determines the equilibrium. Figure 5 presents an example of the firms' decision with regard to the probabilities of effective tracing and public discovery ($p = 2$, $w = 1$, $c = 0.2$, $c_r = 0.07$, $c_T = 0.05$, $c_R = 0.1$, $d_B = 0.9$, and $d_S = 0.2$).

Unlike Figure 1, two of the three boundary lines are neither vertical nor horizontal because the corresponding thresholds $\bar{\bar{\beta}}$ and $\bar{\bar{\bar{\beta}}}$ vary as the tracing effectiveness (α) changes. First, regardless of the effective tracing probability (α), when the chance of public discovery is high enough ($\beta > \bar{\beta}$), S rather invests in responsible sourcing upfront to avoid the cost of damage, and thus NR is the unique equilibrium. Note that this threshold is supplier-driven because it is lower for greater damage to S (d_S) and lower responsible sourcing cost (c_R). Second, on the other hand, when the discovery probability is sufficiently low ($< \bar{\bar{\beta}}$ and $< \bar{\beta}$), B finds tracing too costly or not effective so rather risks not tracing. This second threshold ($\bar{\bar{\beta}}$) is, however,

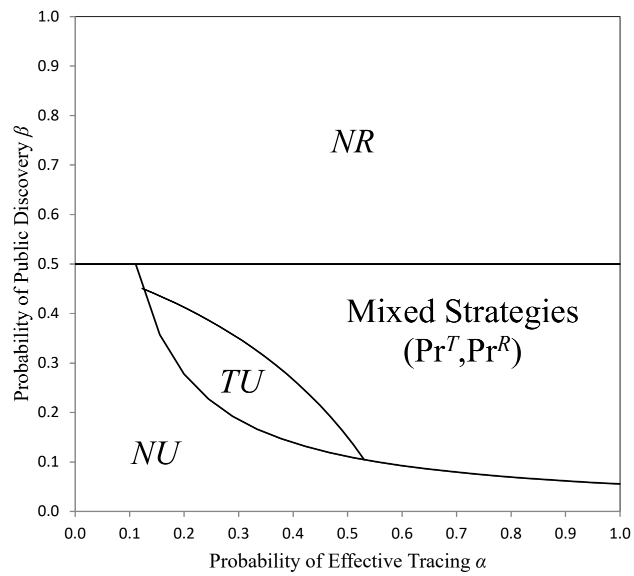
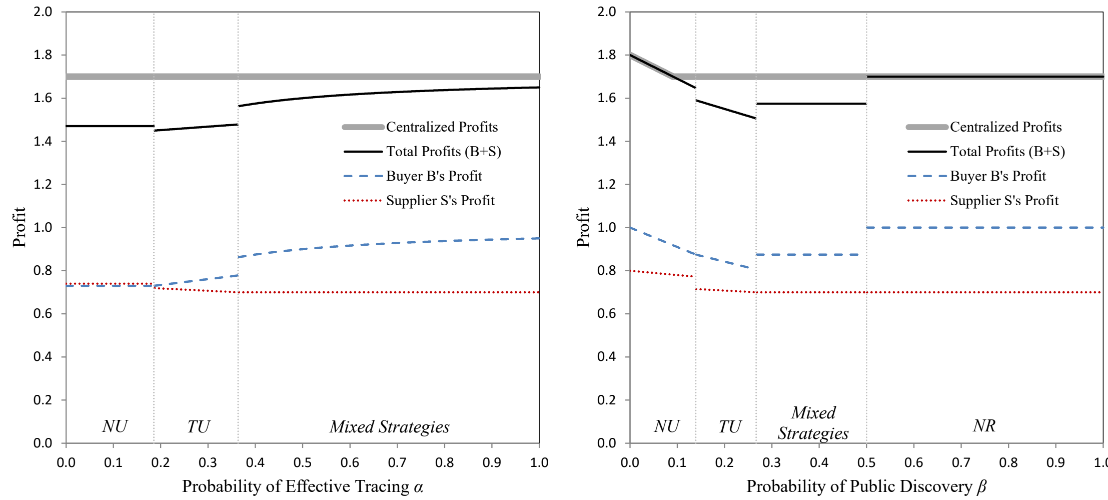


Figure 5: Equilibrium regions in effective tracing and responsible sourcing probabilities

buyer-driven because it is higher for lower effective tracing probability and damage to B (α and d_B) and higher tracing costs (c_T). In other words, in the NU equilibrium, B's decision to not trace (due to low α, low d_B, or high c_T) results in S's choice of unethical sourcing. Third, for low to intermediate risk of public discovery ($\bar{\bar{\beta}} < \beta < \bar{\bar{\bar{\beta}}}$) and intermediate tracing effectiveness (α), B may find tracing rewarding to embark on tracing while S is still willing to risk sourcing unethically (in the TU region). Lastly, for intermediate $\beta \in \left(\max\{\bar{\bar{\beta}}, \bar{\bar{\bar{\beta}}}\}, \bar{\beta}\right)$ but high α, the two firms will adopt mixed strategies with equilibrium tracing and responsible sourcing probability (Pr^T and Pr^R) as characterized in Proposition 1.

We look more closely at this example to understand how the firms modify their strategy as the probabilities change. In Figure 5, when $\alpha = 0.3$, as β increases, the equilibrium changes from NU, to TU, to MS, and finally to NR. Notice that B starts from not tracing, to tracing, to mixed strategies, and finally back to not tracing. S, on the other hand, changes from unethical sourcing, to mixed strategies, and lastly to responsible sourcing (not returning back to Unethical). This illustrates the dynamics of the game that B does not only respond to the change of the factor but also takes into account S's reaction to such a change. Therefore, for high β, B reverts its decision from tracing (if considering only the effect of high β on itself) to not tracing knowing S would source responsibly.

How do these probabilities affect the profit of each firm? The example in Figure 6(a) ($\beta = 0.3$) shows that when the probability of effective tracing (α) is relatively low, profit is level since B does not trace (NU); in the intermediate region, B traces S's unethical sourcing (TU), and its profit rises while S's profit falls. For relatively higher tracing effectiveness,



(a) Probability of effective tracing

(b) Probability of public discovery

Figure 6: Sensitivity of profit to tracing and responsible sourcing costs

both firms adopt mixed strategies (MS), with B's profit increasing while S's profit remaining the same. Therefore, the effects of α on profits are monotone: B benefits while S suffers as the tracing effectiveness improves. On the other hand, as the public discovery probability (β) rises (see Figure 6(b), with $\alpha = 0.3$), the profits of both firms first drop, then B's profit rises while S's profit remains the same. Interestingly, B's profit curve is no longer monotone in the discovery probability. This is because higher publicity only negatively affects B if S continues to source unethically, but it helps boost B's profits if the chance of public discovery is high enough to change S's sourcing from unethical to MS at $\bar{\bar{\beta}} = 0.14$ and from MS to responsible at $\bar{\bar{\bar{\beta}}}$. Besides the individual profits each firm made in the tracing game, Figure 6 also shows how much more profit the supply chain may obtain through coordination against the total (uncoordinated) profits.

Lastly, we explore the possibility of coordination raised earlier, aiming to achieve the first-best solution for the whole supply chain. We consider a contract that allows the buyer to cover part of the supplier's responsible sourcing cost (cost-sharing proportion λ) and impose a punishment on the supplier for any publicized violations that cause reputational damage (penalty Δd_S). For cost sharing, we assume that the buyer has the information regarding whether the supplier sources responsibly or not to subsidize such costs. This may be achieved by the supplier sourcing from third-party certified sources. For example, Epson asks its tier-1 suppliers to source minerals only from conflict-free smelters certified by RMI's Responsible Minerals Assurance Program (Epson, 2020). Hence, the decision reduces to whether the whole supply chain would source responsible or not with no tracing decision involved, that is, Responsible v.s. Uethical sourcing and the profit functions can be expressed as follows:

$$\pi_B^R = p - w - \lambda c_R \tag{13}$$

$$\pi_S^R = w - c - (1 - \lambda)c_R \tag{14}$$

$$\pi_B^U = p - w - \beta\,(d_B - \Delta d_S) \tag{15}$$

$$\pi_S^U = w - c - \beta\,(d_S + \Delta d_S) \tag{16}$$

Proposition 4. *The supply chain can be coordinated to achieve the centralized profit by a cost-sharing and penalty contract with*

- *B sharing λ of S's responsible sourcing cost c_R and*
- *B imposing a penalty of $\Delta d_S(\lambda) \equiv (d_B + d_S)(1 - \lambda) - d_S$ on S if found sourcing unethically for $\lambda \in \left[0, \frac{d_B}{d_B+d_S}\right]$.*

For the coordinated supply chain, when $d_B > \frac{c_R}{\beta} - d_S$, R is the unique equilibrium; otherwise, U is the unique equilibrium.

Proposition 4 characterizes the coordinating cost-sharing and penalty contract and provides a lower bound on the buyer's reputational damage for the coordinated supply chain to also act in the best interest of the society, a responsible supply chain. Even though most internal stakeholders may be primarily concerned with financial performances, for those with a good reputation at risk (high d_B), it is worth collaborating to achieve the best across the triple bottom lines. In practice, to help share responsible sourcing costs, Patagonia is committed to achieving a fair wage instead of unreasonably low prices in their cost negotiations with factories (Patagonia, 2021) and electronics companies pay significantly higher for verified conflict-free minerals than the price for untraceable ones (Enough Project, 2017). On the other hand, for non-compliant suppliers, Costco states in its Supplier Code of Conduct that the suppliers shall be liable for all related damages incurred by Costco, including lost profits (Costco, 2018).

Besides the cost-sharing only and penalty-only contracts, Figure 7 illustrates how a mixture of the two special contracts may be constructed using the penalty scheme function ($\Delta d_S(\lambda)$). Specifically, the buyer may cover more responsible sourcing cost in a more collab-

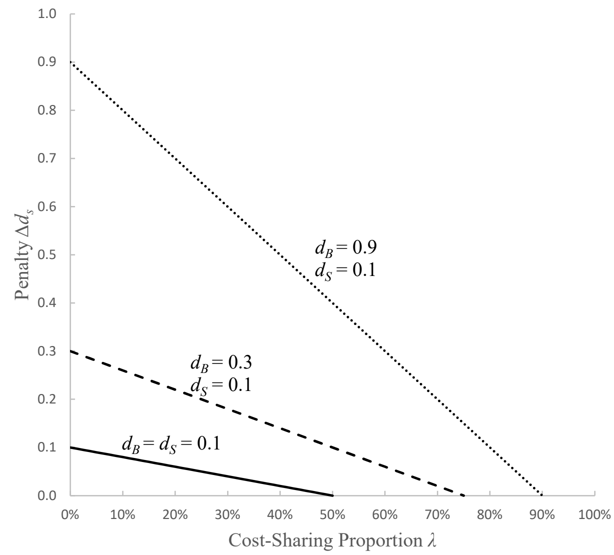


Figure 7: Cost-sharing proportion and penalty to coordinate supply chain

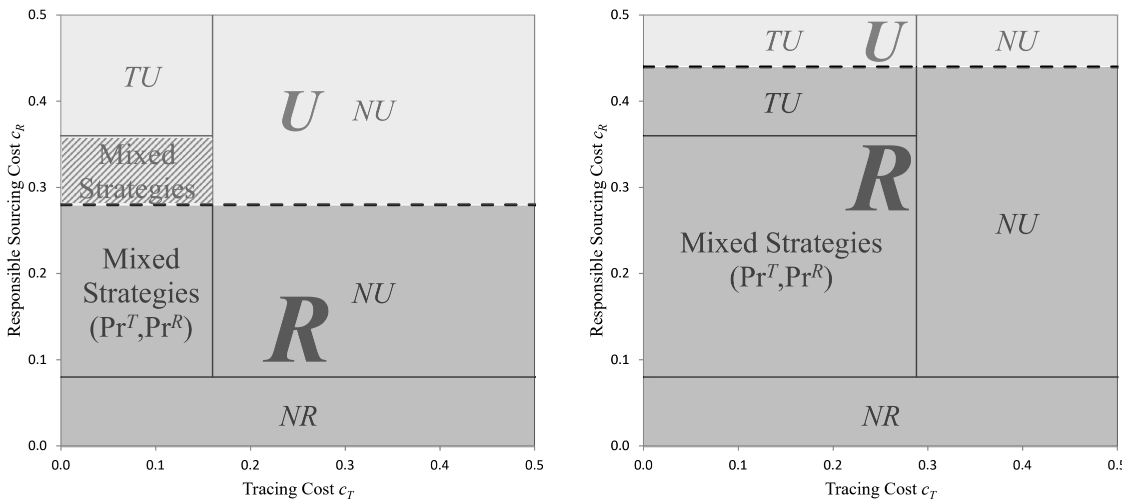
orative relationship with the supplier (up to the proportion $\lambda = \frac{d_B}{d_B+d_S}$, which degenerates to the cost-sharing only contract) or more resort to non-compliance penalty with a less collaborative supplier (up to its full reputational damage d_B, the penalty-only contract). For an equal cost split ($\lambda = 0.5$), a corresponding penalty $\Delta d_S = \frac{d_B - d_S}{2}$ is imposed for any publicized violations so that the supplier's total damage ($\frac{d_B+d_S}{2}$) is exactly half of the supply chain's.

The penalty-only contract may seem rather attractive to the buyer at first glance as it requires no upfront cost-sharing for the coordination. We note that however since many suppliers are (much) smaller than their buyers, it may be worth considering the case of limited liability (penalty) that can be imposed on the supplier:

Corollary 3. *When the supplier's liability is limited by $\overline{\Delta d_S} < d_B$, the buyer then has a minimum cost-sharing proportion $\frac{d_B - \overline{\Delta d_S}}{d_B + d_S} > 0$ to cover for the coordination.*

Corollary 3 suggests that a big buying company like Nike should pay for a fair portion of its small supplier's responsible sourcing cost, or the supplier would source unethically because of the high cost and limited liability. As an example in Figure 7, for the dotted line case ($d_B = 0.9 \gg d_S = 0.1$), if the supplier's liability is limited by 0.1, then the buyer should at least cover 80% or more of the responsible sourcing cost.

We would like to note that a coordinated supply chain may not always be more responsible than the non-coordinated one. As seen in Figure 8(a), part of the mixed-strategy Nash equilibrium region under the non-coordinated scheme might fall into the Unethical equilibrium region under the coordinated one, which is worse from the social perspective. However,



(a) Not socially optimal

(b) Socially optimal

Figure 8: Coordinated equilibrium in tracing and responsible sourcing costs

a more responsible supply chain may be obtained under coordination as seen in Figure 8(b) when some sufficient condition is met.

Corollary 4. *For $c_T > \alpha(c_R - \beta d_S)$, the coordinated supply chain is (weakly) more responsible than the non-coordinated chain.*

The condition is likely to hold when the tracing cost is high and the probability of internal discovery is low, like in the case of conflict minerals as mentioned in the introduction Chasan (2015). NGOs may also help ensure responsibility for coordinated chains by exerting more effort uncovering unethical sourcing (improving β), as well as publicly naming and shaming unethical suppliers (raising d_S).

4. Conclusions

Theoretical Contributions

In this paper, we studied the strategic interaction of a buyer's tracing decision and its supplier's responsible sourcing decision under a transparency regulation (that is, whether met or not, a binary decision) as opposed to the more voluntary environments examined in the earlier works like Plambeck and Taylor (2016) and Caro *et al.* (2018) (i.e., more is better, a continuous-variable decision, not appropriate in the highly regulated environments). We also explicitly consider corrective actions made available for an at-risk supplier to remediate any responsibility issues identified by the buyer's tracing as mostly seen in practice and suggested by many regulation guidelines (Harris, 2015; UK Home Office, 2020; OECD, 2016), instead of immediate separation mostly assumed in the literature (e.g., Plambeck and Taylor 2016; Lu and Tomlin 2021). We establish that under rather general conditions, the two firms will adopt mixed strategies in equilibrium, a departure from the more common pure-strategy equilibria. To the best of our knowledge, we are the first to utilize the mixed-strategy equilibrium concept to study the effect of regulations in supply chain traceability on responsible sourcing and the roles of different external and internal stakeholders. As detailed next in the summary of implications below, our results contribute to the literature by showing that under rather general conditions, more responsible sourcing may be achieved through

- selected efforts exerted by the external stakeholders possibly without the high compliance and regulatory costs and
- a menu of contracts incorporating both cost sharing and penalty between the internal stakeholders based on their collaborative relationship and relative sizes.

Implications for Stakeholders

Our mixed-strategy results provide several practical implications for both the internal and external stakeholders. First, in a game of strategy, the often overlooked strategic effect of an action can negate and sometimes even outweigh the more obvious direct effect on the players' decisions. This leads to some seemly counter-intuitive findings as summarized below in Table 2:

Second, Table 2 readily shows that a strategic action can have very different effects on responsible sourcing and tracing. For instance, raising the effectiveness of tracing or public

Strategy	Responsible Sourcing	Tracing
Reducing tracing cost	POSITIVE	no effect
Reducing responsible sourcing cost	no effect	NEGATIVE
Reducing cost of corrective actions	no effect	POSITIVE
Improving probabilities of discovery	POSITIVE	NEGATIVE
Increasing damage on buyer	POSITIVE	no effect
Increasing damage on supplier	no effect	NEGATIVE

Table 2: Effects of strategies

discovery has opposite effects on the two firms' decisions: the buyer traces less while the supplier source more responsibly. We summarize below some actions and examples that make supply chains more responsible:

- reducing tracing costs for the buyers, which may be achieved through government subsidies, joint audits or third-party certification, e.g., the Alliance for Bangladesh Work Safety in the apparel industry and Responsible Minerals Assurance Program in the electronics industry,
- increasing potential brand damage to the buyers, which can be done through governments/NGOs making more public awareness of any unethical supply chain practices, consumers boycotting the brands, or investors pulling funds away from these companies, like Business and Human Rights Resource Centre (2021) recommending the UK government to increase penalties on the buyers associated with human and labor rights violations, such as import bans and no participation in public procurement, and
- increasing the likelihoods of both internal and external discoveries of unethical sourcing, which may be done through better auditing practices such as rotating audit firms and including female auditors as suggested by Short and Toffel (2021).

Third, Figure 9 shows schematically how a coordinating contract incorporating cost sharing and penalty may be constructed between the two internal stakeholders based on their collaborative relationship and relative sizes. In general, the more collaborative relationship the two have, the more responsible sourcing cost is shared, and the less penalty is imposed. The reverse (less collaborative relationship) should be executed with caution by taking into

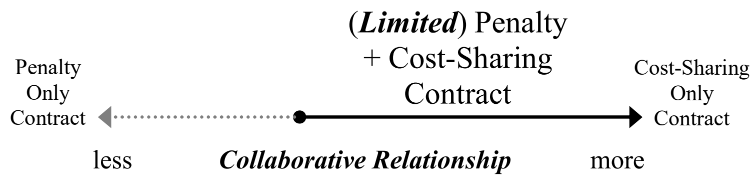


Figure 9: Coordinating contract with collaborative cost-sharing and limited liability

account the relative sizes of the two players. A big buyer should pay for a fair portion of its small supplier's responsible sourcing costs as in the case of Patagonia (Patagonia, 2021), or the supplier would source unethically because of the high cost and limited liability as seen in the opening case of Nike. Lastly, while a coordinated supply chain may not necessarily be more responsible than the non-coordinated one, some simple sufficient conditions (high tracing cost and low likelihood of internal discovery as in the case of conflict minerals) can ensure achieving both social and financial optimalities. In conclusion, our analysis helps the stakeholders understand why many supply chain transparency regulations may not work as intended and how to make supply chains more responsible, possibly without the high compliance and regulatory costs.

Limitations and Future Research

Our stylized model can be extended in several directions. First, given that a few transparency regulations have been implemented for several years, it will be worthwhile to empirically validate some of our key findings through the help of text mining approaches since the raw data available is primarily in text and unstructured. Second, the coordinating mechanism may be further extended to incorporate other risk-sharing contracts like contingency/deferred payment, avoiding enforcing a sizeable penalty on a small supplier with limited liability.

Our work also has certain limitations, which may be relaxed in several ways. We assumed a simultaneous-move game since our focus is to provide practical implications for various stakeholders to make better strategic policy-making, monitoring, and investing decisions at a more macro level where the firms cannot observe each other's actions. On the other hand, a sequential-move (dynamic) framework may be useful to study procurement contract design problems where one firm may imperfectly observe the other's effort level. Furthermore, the dynamic framework may also help study the causal effect of the buyer's tracing policy on the supplier's responsible sourcing and participating decisions. Additionally, our results were based on the assumption of only one supplier while, in reality, there can be multiple suppliers available with different pricing and capabilities in responsible sourcing. The buyer then faces a portfolio problem of how much demand to allocate to each supplier, focusing on balancing its payoffs and risk exposure.

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Appendix

Proof of Proposition 1.

$$\begin{aligned}
\pi_B^{NR} > \pi_B^{TR} &\iff c_T > 0 \\
\pi_B^{TU} > \pi_B^{NU} &\iff c_T < \bar{c}_T \equiv \alpha\beta d_B \\
\pi_S^{NR} > \pi_S^{NU} &\iff c_R < \bar{c}_R \equiv \beta d_S \\
\pi_S^{TR} > \pi_S^{TU} &\iff c_R < \bar{\bar{c}}_R \equiv \beta d_S + \left(\frac{\alpha}{1-\alpha}\right) c_r
\end{aligned}$$

Since tracing is costly ($c_T > 0$) and depending on c_T and c_R with respect to the three thresholds ($\bar{c}_T$, $\bar{c}_R < \bar{\bar{c}}_R$), there are total 6 possible cases ([1]-[6]) to consider.

a. [1] When $c_T < \bar{c}_T$ and $c_R < \bar{c}_R < \bar{\bar{c}}_R$, $\pi_B^{NR} > \pi_B^{TR}$, $\pi_B^{TU} > \pi_B^{NU}$, $\pi_S^{NR} > \pi_S^{NU}$, and $\pi_S^{TR} > \pi_S^{TU}$, so NR is the unique equilibrium.

[2] When $c_T > \bar{c}_T$ and $c_R < \bar{c}_R < \bar{\bar{c}}_R$, $\pi_B^{NR} > \pi_B^{TR}$, $\pi_B^{TU} < \pi_B^{NU}$, $\pi_S^{NR} > \pi_S^{NU}$, and $\pi_S^{TR} > \pi_S^{TU}$, so NR is also the unique equilibrium.

Therefore, NR is the unique equilibrium when $c_R < \bar{c}_R (< \bar{\bar{c}}_R)$, regardless of c_T.

b. [3] When $c_T > \bar{c}_T$ and $\bar{c}_R < c_R < \bar{\bar{c}}_R$, $\pi_B^{NR} > \pi_B^{TR}$, $\pi_B^{TU} < \pi_B^{NU}$, $\pi_S^{NR} < \pi_S^{NU}$, and $\pi_S^{TR} > \pi_S^{TU}$, so NU is the unique equilibrium.

[4] When $c_T > \bar{c}_T$ and $\bar{c}_R < \bar{\bar{c}}_R < c_R$, $\pi_B^{NR} > \pi_B^{TR}$, $\pi_B^{TU} < \pi_B^{NU}$, $\pi_S^{NR} < \pi_S^{NU}$, and $\pi_S^{TR} < \pi_S^{TU}$, so NU is also the unique equilibrium.

Therefore, NU is the unique equilibrium when $c_T > \bar{c}_T$ and $c_R > \bar{c}_R$, regardless of $\bar{\bar{c}}_R$.

c. [5] When $c_T < \bar{c}_T$ and $c_R > \bar{\bar{c}}_R$, $\pi_B^{NR} < \pi_B^{TR}$, $\pi_B^{TU} < \pi_B^{NU}$, $\pi_S^{NR} < \pi_S^{NU}$, and $\pi_S^{TR} < \pi_S^{TU}$, so TU is the unique equilibrium.

d. [6] When $c_T < \bar{c}_T$ and $\bar{c}_R < \bar{\bar{c}}_R < c_R$, $\pi_B^{NR} < \pi_B^{TR}$, $\pi_B^{TU} < \pi_B^{NU}$, $\pi_S^{NR} < \pi_S^{NU}$, and $\pi_S^{TR} > \pi_S^{TU}$, so there exists no pure-strategy equilibrium.

To solve for the mixed-strategy Nash equilibrium, assume B traces its sourcing with probability $\Pr^T$ and S supplies responsibly with probability $\Pr^R$. In equilibrium, given S's mixed strategy $(\Pr^R, 1 - \Pr^R)$ for responsible and unethical sourcing, B's expected profit between tracing and not tracing must be the same (Fudenberg and

Tirole, 1991).

$$\begin{aligned}
&\mathbb{E}\left[\pi_B^T\right] = \mathbb{E}\left[\pi_B^N\right] \\
\iff &\Pr^R \pi_B^{TR} + (1-\Pr^R)\pi_B^{TU} = \Pr^R \pi_B^{NR} + (1-\Pr^R)\pi_B^{NU} \\
\iff &\Pr^R\left[p - w - c_T\right] + (1-\Pr^R)\left[\alpha(p-w) + (1-\alpha)(p - w - \beta d_B) - c_T\right] \\
&= \Pr^R\left[p - w\right] + (1-\Pr^R)\left[p - w - \beta d_B\right] \\
\iff &\Pr^R = 1 - \tfrac{c_T}{\alpha\beta d_B} \in (0,1) \text{ for } 0 < c_T < \bar{c}_T
\end{aligned}$$

Similarly, given B's mixed strategy $(\Pr^T, 1-\Pr^T)$ for tracing and not tracing its sourcing, S's expected profit between supplying responsibly and unethically must be the same.

$$\begin{aligned}
&\mathbb{E}\left[\pi_S^R\right] = \mathbb{E}\left[\pi_S^U\right] \\
\iff &\Pr^T \pi_S^{TR} + (1-\Pr^T)\pi_S^{NR} = \Pr^T \pi_S^{TU} + (1-\Pr^T)\pi_S^{NU} \\
\iff &\Pr^T\left[w - c - c_R\right] + (1-\Pr^T)\left[w - c - c_R\right] \\
&= \Pr^T\left[\alpha(w - c - c_R - c_r) + (1-\alpha)(w - c - \beta d_S)\right] + (1-\Pr^T)\left[w - c - \beta d_S\right] \\
\iff &\Pr^T = \tfrac{c_R - \beta d_S}{\alpha(c_R + c_r - \beta d_S)} \in (0,1) \text{ for } \bar{c}_R < c_R < \bar{\bar{c}}_R
\end{aligned}$$

The expected profits can be obtained by using the equilibrium probabilities: $\pi_B^{MS} = \Pr^T \Pr^R \pi_B^{TR} + \Pr^T(1-\Pr^R)\pi_B^{TU} + (1-\Pr^T)\Pr^R \pi_B^{NR} + (1-\Pr^T)(1-\Pr^R)\pi_B^{NU} = p - w - \frac{c_T}{\alpha}$ and $\pi_S^{MS} = \Pr^T \Pr^R \pi_S^{TR} + \Pr^T(1-\Pr^R)\pi_S^{TU} + (1-\Pr^T)\Pr^R \pi_S^{NR} + (1-\Pr^T)(1-\Pr^R)\pi_S^{NU} = w - c - c_R$.

□

Proof of Corollary 1. The results follow directly from taking partial derivatives of the two probability functions, $\Pr^T = \frac{c_R - \beta d_S}{\alpha(c_R + c_r - \beta d_S)}$ and $\Pr^R = 1 - \frac{c_T}{\alpha\beta d_B}$, with respect to the parameters:

a. $\frac{\partial \Pr^T}{\partial c_R} = \frac{\alpha c_r}{[\alpha(c_R + c_r - \beta d_S)]^2} > 0$, $\frac{\partial \Pr^T}{\partial c_r} = \frac{-\alpha(c_R - \beta d_S)}{[\alpha(c_R + c_r - \beta d_S)]^2} < 0$, $\frac{\partial \Pr^T}{\partial d_S} = \frac{-\alpha\beta c_r}{[\alpha(c_R + c_r - \beta d_S)]^2} < 0$, $\frac{\partial \Pr^T}{\partial \alpha} = \frac{-\alpha(c_R - \beta d_S)}{[\alpha(c_R + c_r - \beta d_S)]^2} < 0$, and $\frac{\partial \Pr^T}{\partial \beta} = \frac{-\alpha c_r d_S}{[\alpha(c_R + c_r - \beta d_S)]^2} < 0$.

b. $\frac{\partial \Pr^R}{\partial c_T} = -\frac{1}{\alpha\beta d_B} < 0$, $\frac{\partial \Pr^R}{\partial d_B} = \frac{c_T\alpha\beta}{(\alpha\beta d_B)^2} > 0$, $\frac{\partial \Pr^R}{\partial \alpha} = \frac{c_T\beta d_B}{(\alpha\beta d_B)^2} > 0$, and $\frac{\partial \Pr^R}{\partial \beta} = \frac{c_T\alpha d_B}{(\alpha\beta d_B)^2} > 0$.

□

Proof of Proposition 2. The results follow directly from taking partial derivatives of the two probability functions, $\Pr^T = \frac{c_R - \beta d_S}{\alpha(c_R + c_r - \beta d_S)}$ and $\Pr^R = 1 - \frac{c_T}{\alpha\beta d_B}$, with respect to the parameters:

a. $\pi_B^{NR} = p - w > \pi_B^{TR} = p - w - c_T > \pi_B^{MS} = p - w - \frac{c_T}{\alpha}$ for $c_T > 0$ and $\alpha \in (0,1)$. $\pi_B^{MS} = p - w - \frac{c_T}{\alpha} > \pi_B^{TU} = (p-w) + (1-\alpha)\beta d_B - c_T > \pi_B^{NU} = p - w - \beta d_B$ for $c_T < \bar{c}_T$.

b. $\pi_S^{NR} = \pi_S^{MS} = \pi_S^{TR} = w - c - c_R$. $\pi_S^{NU} = w - c - \beta d_S > \pi_S^{MS} = w - c - c_R > \pi_S^{TU} = w - c - \alpha(c_R + c_r) - (1-\alpha)\beta d_S$ for $\bar{c}_R < c_R < \bar{\bar{c}}_R$.

□

Proof of Corollary 2. The results follow directly from taking partial derivatives of the two profit functions, $\pi_B^{MS} = p - w - \frac{c_T}{\alpha}$ and $\pi_S^{MS} = w - c - c_R$, with respect to the parameters:

a. $\frac{\partial \pi_B^{MS}}{\partial p} = 1 > 0$, $\frac{\partial \pi_B^{MS}}{\partial \alpha} = \frac{c_T}{\alpha^2} > 0$, $\frac{\partial \pi_B^{MS}}{\partial w} = -1 < 0$, and $\frac{\partial \pi_B^{MS}}{\partial c_T} = -\frac{1}{\alpha} < 0$.

b. $\frac{\partial \pi_S^{MS}}{\partial w} = 1 > 0$, $\frac{\partial \pi_S^{MS}}{\partial c} = -1 < 0$, and $\frac{\partial \pi_S^{MS}}{\partial c_R} = -1 < 0$.

□

Proof of Proposition 3. Notice that the structure of Proposition 3 is parallel to that of Proposition 1, and the equilibrium regions are analogous. So it is sufficient to show that the conditions are equivalent by rearrangement.

a. $c_R < \bar{c}_R = \beta d_S \iff \beta > \frac{c_R}{d_S} \equiv \bar{\beta}$.

b. $c_T > \bar{c}_T = \alpha\beta d_B \iff \beta < \frac{c_T}{\alpha d_B} \equiv \bar{\bar{\beta}}$, and $c_R > \bar{c}_R \iff \beta < \bar{\beta}$. Therefore, $\beta < \min\{\bar{\beta}, \bar{\bar{\beta}}\}$.

c. $c_T < \bar{c}_T \iff \beta > \bar{\bar{\beta}}$, and $c_R > \bar{\bar{c}}_R = \beta d_S + \left(\frac{\alpha}{1-\alpha}\right) c_r \iff \beta < \frac{c_R}{d_S} - \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{c_r}{d_S}\right) \equiv \bar{\bar{\bar{\beta}}}$. Therefore, $\bar{\bar{\beta}} < \beta < \bar{\bar{\bar{\beta}}}$.

d. $c_T < \bar{c}_T \iff \beta > \bar{\bar{\beta}}$, and $\bar{c}_R < c_R < \bar{\bar{c}}_R \iff \bar{\bar{\bar{\beta}}} < \beta < \bar{\beta}$. Therefore, $\max\{\bar{\bar{\beta}}, \bar{\bar{\bar{\beta}}}\} < \beta < \bar{\beta}$.

□

Proof of Proposition 4. We first note that for a centralized supply chain, the only decision to make is whether to source *R*esponsibly or *U*nethically. Costly tracing is no longer needed to uncover unethical sourcing in this case since there is only one decision maker and it knows its own decision made. Therefore, only two centralized profit functions remain valid:

$$\pi_{BS}^{NR} = p - c - c_R \tag{A.1}$$

$$\pi_{BS}^{NU} = p - c - \beta(d_B + d_S) \tag{A.2}$$

When $d_B > \frac{c_R}{\beta} - d_S$, $\pi_{BS}^{NR} > \pi_{BS}^{NU}$, so NR is the unique equilibrium. Otherwise, $\pi_{BS}^{NR} < \pi_{BS}^{NU}$ and thus NU is the unique equilibrium. To induce S to source responsibly for $d_B > \frac{c_R}{\beta} - d_S$ as in the centralized case, let λ be B's cost-sharing portion of c_R and rewrite S's profits as following:

$$\pi_S^R = w - c - (1-\lambda)c_R \tag{A.3}$$

$$\pi_S^U = w - c - \beta\left(d_S + \Delta d_S(\lambda)\right) \tag{A.4}$$

When $\Delta d_S(\lambda) = (d_B + d_S)(1-\lambda) - d_S$, $\pi_S^R > \pi_S^U$ iff $d_B > \frac{c_R}{\beta} - d_S$. □

Proof of Corollary 3. This follows directly by rearranging $\Delta d_S(\lambda) = (d_B + d_S)(1-\lambda) - d_S \leq \overline{\Delta d_S}$ as $\lambda \geq \frac{d_B - \overline{\Delta d_S}}{d_B + d_S}$. □

Proof of Corollary 4. For the uncoordinated NR equilibrium case, $c_R < \beta d_S$ implies $\frac{c_R}{\beta} - d_S < 0 < d_B$, the condition for the R equilibrium as specified in Proposition 4. For the MSNE case, $c_T < \alpha\beta d_B$ and if $c_T > \alpha(c_R - \beta d_S)$, then it implies $d_B > \frac{c_T}{\alpha\beta} > \frac{c_R}{\beta} - d_S$, again satisfying the R-equilibrium condition. The remaining two cases, TU and NU, both involve Unethical sourcing, so the coordinated supply chain would do at least as good (U) or better (R). □