Responsible Capacity Development

Pavel Izhutov *

October 2017

Long-term relationships are generally believed to incentivize investments better than short-term relationships. We show that while this is true for *quality* investments, it is not always true for *responsibility* investments. In particular, when a reliable and an unreliable supplier compete for the business of a responsible buyer, the buyer achieves higher responsibility by offering a *short-term* commitment to the unreliable supplier. The result is reversed and follows standard intuition only if the buyer cannot control purchase prices. Optimal contracts are derived in closed form and are linked to prevailing corporate strategies.

Key words: supply chain management, responsible contracting, responsible sourcing, sustainability

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* Axio Inc., San Francisco, CA, 94108 ; Graduate School of Business, Stanford University, Stanford, CA, 94305, izhutov@stanford.edu

1. Introduction

Ensuring responsible production is becoming increasingly important. However, it is not always easy to find ethical suppliers. Indeed, suppliers that procure responsibly are few and typically more expensive. While some companies are ready to source from both responsible and irresponsible suppliers, ethical companies fully commit to responsible sources (e.g., Starbucks[1]). To drive procurement costs down while conforming to responsibility standards, ethical companies have to incentivize *investments in responsible capacity* in their supply chains. The more responsible capacity on the supply side, the higher the competition between suppliers and the lower the procurement costs.

While there exist different strategies to encourage responsible investments, in recent years, a number of large multinational companies such as Nike[2], Wal-Mart[3] and L'Oréal [4], have initiated the move towards long-term relationships and contracts with their suppliers. There is an intuitive appeal that long-term relationships and contracts would indeed be appropriate steps to make. First, while the dominant forms of procurement are based on short-term purchases such as in spot markets, a large number of violations by suppliers have recently been identified by major companies like Apple, Samsung, Disney and Zara (Plambeck (2012)). Hence, it may suggest that using the spot market for purchasing may not be the best way to do sourcing. Second, a responsible production process is not something that a supplier can develop overnight - it results from the cumulative continual efforts by the supplier. Thus, the buyer's long-term sourcing commitment may give confidence to suppliers that their responsible efforts would eventually pay off. Finally, there are still many buyers who do not practice responsible sourcing. An insufficient mass of responsible buyers essentially makes the investments of suppliers for responsible production to be relationship-specific. That is, upon the potential discontinuation of the relationship with the responsible buyer, those investments may not have much value in the market. The existence of such a possibility is another argument for using long-term relationships.

There has been a rich literature that praises the use of long-term arrangements for buyers and suppliers as an effective sourcing mode in various contexts. Liker (2004) described the Toyota Way,

[1] "Starbucks is proud to have reached the milestone of 99% of our coffee ethically sourced" (Starbucks (2017a)), "We are committed to buying 100 percent ethically sourced coffee" (Starbucks (2017b))

[2] "Globally, we have made progress in optimizing our factory base by focusing on rigorous screening and by assessing the performance of contract factories. We have moved toward establishing long-term relationships with fewer factories as trusted partners, rather than having short-term transactional relationships with a larger number of factories."(Nike (2012))

[3] "To boost supplies of organic cotton and help more farmers make the transition from conventional to organic farming, Wal-Mart has begun making longer-term commitments. For example, rather than working season to season, as the company has done in the past, it made a five-year commitment to buy organic cotton from a group of farmers."(Plambeck and Denend (2008))

[4] "Through L'Oréal Buy and Care Program, the Group is committed to build long-term sustainable relationships with its suppliers, based among others on the protection of environment, social development and economic development."(L'Oreal (2013))

which has been used effectively by Toyota in managing its suppliers. One of the cornerstones of the Toyota Way is long term philosophy, or managing with a long term view. Others suggested long term relationships could foster open communication and cooperation (Chen et al. (2004)), and could result in quality improvement and continuous cost reduction (e.g., Kalwani and Narayandas (1995); Newman (1988)). Another benefit cited for long term relationships is tighter supplier involvement to accelerate new product development (e.g., Ragatz et al. (1997)). Swinney and Netessine (2008) show that under the possibility of the supplier's default, long-term contracts may be more preferable to short-term ones.

Despite the rich literature on the value of long term buyer-supplier commitment, it is not clear as to how the responsibility performance (i.e., compliance to environmental, social and ethical standards) of suppliers would be different based on short-term or long-term commitments. The aim of this paper is to fill in this gap. In particular, we present a novel model that compares three sourcing modes (spot-market sourcing, long-term relationships and long-term contracts). The model is used to examine and critically evaluate the effect on supplier responsibility under the initiatives by multinationals to move to long-term relationships with their suppliers. We show that standard intuition holds only for quality investments but does not hold for responsibility investments. We consider a setting in which responsibility investments do not directly create consumer value but rather increase the responsible capacity (e.g., facilities that do not use child labor, or factories with acceptable working conditions, lands with no toxic inputs, etc.). These investments do not increase the product value per se (like quality investments) but rather drive procurement costs down by creating a stronger supply-side competition for the buyer's business. Indeed, if the responsible capacity is abundant, the buyer can easily find an ethical supplier and negotiate a low purchase price. If the responsible capacity is scarce, the buyer will have to pay more in order to live up to his responsibility standards. Long-term relationships are exclusive by nature and are therefore at odds with the benefit of the increased competition created by responsible investments. Since an intensified supply-side competition is the only (commercial) benefit that responsible investments create (unlike quality investments), spot market sourcing turns out to be more attractive for responsibility investments than long-term relationships or contracts.

The sourcing decision by a buyer is captured in a dynamic discrete infinite-period model. The buyer has a choice between a reliable supplier which is always responsible and an unreliable supplier (thereafter, "supplier"), which can improve her responsibility performance over time. The supplier determines how much to invest in a responsible production process in each period. We assume that responsible production is not a zero-one indicator, and there can be an aggregate intensity measure which we call the "responsibility level." To see why responsible production is not a zero-one or black and white measure, we give some simple examples. Consider the emission of toxic materials;

the level can be measured. Next, the extent of excessive overtime can also be measured. Finally, the comfort and safety of the production environment can also be evaluated based on some scale measure. Suppliers can make investments to influence the responsibility level. One may think about investments in waste water treatment, dust control, safety in production environment, employee training, better dormitories for employees, etc. The performance in these responsibility dimensions is aggregated into and represented by the responsibility level which defines the probability of the violation revelation. We also assume that investments have an additive impact on the responsibility level, i.e., the investment in the current period will contribute to the responsibility level of this period, as well as all subsequent periods in a discounted fashion. To study the impact of supplier-buyer relationships on responsible production, we deliberately ignore the other impacts of long term relationships that we mentioned earlier (such as trust, information sharing, and new product development). This allows us to sharply focus on responsibility levels under different sourcing policies. A buyer's sourcing decision in each period is based on (1) the responsibility level of the supplier, (2) the random shock in costs of the reliable and unreliable suppliers, and (3) the sourcing policy in place. The higher the responsibility level of the supplier, the higher the chance that the supplier would be qualified for sourcing by the buyer. In this way, the responsibility level of the supplier acts as a lever for the buyer to influence the supplier's responsible behaviors. The supplier's behavior (investments) are unobservable but their outcome can be be revealed. When the responsibility level is not at a satisfactory level, the supplier may not qualify to be used by the buyer as its supplier. In fact, this tends to be a common practice used by many companies, such as Starbucks (Starbucks (2013)). Whenever the violations are revealed, the trade is discontinued until the issue is solved. Additionally, according to the survey conducted by Supply Chain Management World (Lee et al. (2012)), almost 50% of 1,227 executives named the termination of business as the penalty for breach of social and environmental standards. Uncertainty in the model largely driven by regulatory risks and suppliers' cost competition is in line with the risk structure of today's supply chains[5]. Finally, relationship management, which is at the core of the model, is considered the top-2 "procurement tactic to generate most business value over next 18 months" (Lee et al. (2015)).

The main tradeoff studied in the paper is as follows. On the one hand, a long-term relationship ensures the steady business upon responsibility compliance and thereby encourages responsible investments. On the other hand, a long-term relationship reduces the competition between the unreliable and reliable suppliers. In fact, the higher the responsibility compliance, the higher the reduction in competition, since perfect compliance combined with the long-term relationship guarantees business for the unreliable supplier *regardless* of her competitiveness. Interestingly, there is no

[5] price volatility and regulatory risks are among top3 supply chain risk concerns over the next 3 years, shared by more than 90% of supply chain professionals (Lee et al. (2015))

such a tradeoff for quality investments, since quality investments directly increase product margins and therefore increase the supplier's competitiveness.

Responsibility investments as defined in this paper are such that they are necessary for the compliance but they do not directly influence the price of the product. The price level is, instead, defined by the responsibility standards to which the ethical buyer commits. Thus responsibility investments are profitable only because they expand the pool of the compliant supply and thereby reduce the procurement costs. Such relationship between the profit and investments is typical for responsibility areas with "zero tolerance" enforcement from ethical buyers (e.g., Starbucks), in which violations cannot be traded off by price. Therefore this definition of responsible investments allows to focus on some of the most troublesome and hardly measurable areas of responsibility (e.g., child labor and fair employee treatment). One could also argue that some sectors of the digital economy (ethical news reporting, software integrity, privacy and data security) are also highly sensitive to responsibility investments of this type.

2. Relevant literature.

Poor responsibility performance is often the result of misaligned incentives. Besides, the problem is often exacerbated by the lack of information in the supply chains. A significant number of researchers study the interplay between the two.

Imperfect information and incentives. Kim (2015) finds that inspection frequency and its penalty size are complementary instruments, rather than substitutes, for the disclosure of non-compliance cases at the production site. Plambeck and Taylor (2016) show that increasing an audit frequency or supplier's margin may actually induce hiding and reduce compliance. Aral et al. (2014) find that current industry practice of "all or none" audits can be improved via selective auditing. Chen and Lee (2016) demonstrate that supplier certification, process audits, and contingency payments are complimentary to each other, with supplier certification being the most efficient one if used alone. Chen et al. (2015) study complementarities between audits performed by buyers and NGOs and the role of the suppliers's list disclosure by the buyer. Chen and Slotnick (2015) find that a firm's decision to disclose supply sources should take into account actions of the competitor and their effects on a consumer market. Cho et al. (2015) show that pricing and inspection strategies work as strategic complements in combating child labor. They also find that a zero-tolerance policy against child labor may be necessary to prevent inadvertent induction of child labor in case of the transparent inspection policy. This paper also contributes to this branch of literature as in our model the responsible investments are not observable. At the same time, the multi-period relationship horizon allows to condition the future business on stochastically revealed outcome of all past investments, thus creating an incentive to invest in every period. In that sense, our model is close to the long-term investment and relational contracting literature discussed next.

Relational and long-term contracting. Supply chain players can often align incentives with the motive to keep good and robust relationships with each other. For example, Taylor and Plambeck (2007) find that properly structured relational contracts can motivate capacity investment. Tunca and Zenios (2006) analyze competition between procurement auctions and relational contracts and found market and product parameters that favor one or the other. Belavina and Girotra (2012) explain the success of supply intermediaries like Li&Fung by their implicit role as relationship managers providing the spot market-like flexibility for the buyer and long-term commitments for suppliers. Swinney and Netessine (2008) show that long-term contracts may prevent the necessity for a costly switch from a bankrupted supplier by essentially smoothing her budget constraints. Li and Debo (2009) note that long-term contracts induced more aggressive bidding from suppliers which therefore gave away larger information rents. Cohen and Agrawal (1999) study a multi-stage model and considered a number of tradeoffs affecting the optimal choice of sourcing arrangement. In particular, they show that, when prices are volatile and risk aversion is present, long-term contracts with pre-committed prices are more favorable. Tang (1999) provides an excellent discussion of different types of buyer-supplier relationships from a practical perspective. Locke et al. (2007) finds that short-term contracts result in diminished influence on suppliers due to decreased buyer's ability to monitor the production process and working conditions.

Incentivizing investments. The link between the sourcing strategy of the buyer and the investment response of the seller, analyzed in our model, has also been studied in economic literature. For example, in military contracts, Rob (1986) argues that the R&D investment would be optimal if the R&D part is sole-sourced and the later stages of procurement are sourced competitively; Guriev and Kvasov (2005) find that efficient investment can be incentivized via a renegotiation-proof perpetual contract that allows unilateral termination with advance notice. Crawford (1988) concludes that short-term contracts distorted investment decisions in the case of irreversible relationship-specific investments.

The operations management literature, in contrast, is scarce on incentives for dynamic investment decisions, i.e., repetitive decisions that could impact the current period as well as the ones in the long-run. A rare example is Bernstein and Kok (2009) who considers investments for cost-reduction under cost-contingent and target-price contracts. Most of the models on investments, however, have been limited to one-shot actions with immediate cost and return.

Responsibility and sourcing strategies. Another group of authors put their attention to sourcing strategies. In particular, Lewis et al. (2012) studies a problem in which a buyer and a seller have private information about stochastically evolving demand and supply conditions. A supply agreement could then be designed to induce efficient supplier development investments by the retailer. Guo et al. (2015) analyze the interplay between sourcing (responsibly, non-responsibly or both at the same time) and market positioning (selling to all consumers vs socially conscious ones) and identify conditions that define optimal combination of the sourcing and selling strategy. They also find that from regulatory perspective penalizing the buyer is more robust than influencing incentives of consumers. Agrawal and Lee (2016) study the tradeoffs between "sustainable preferred" and "sustainable required" sourcing policies w.r.t inducing the sustainable procurement process by supplier. Porteous et al. (2015) used the survey data collected by SCM World to identify effectiveness of reward and penalty mechanisms that buyers use to incentivize suppliers. Promises of increased business and responsibility training in return to increased responsible performance, were found particularly useful. Orsdemir et al. (2016) study vertical integration as a tool to induce responsibility in the supply chain. Agrawal and Bellos (2015) analyze the impact of service business models on responsibility improvement.

A number of researchers also examine how supply chain structure and the business ecosystem may influence responsibility. In particular, Huang et al. (2016) study the management of social responsibility in multi-tier supply chains, differentiating between delegation, control and "no effort" strategies of the buyer. Belavina and Girotra (2015) study how supply network topologies influence relational sourcing, which, as noted above, is important for responsibility compliance. Gui et al. (2015) analyzes efficient implementation of collective extended producer responsibility, a regulation tool that facilitates post-use collection, recycling and disposal of products. Kraft et al. (2013) focus on how pressure from NGOs can influence responsibility performance in the industry.

Our paper is close in spirit to the papers of Lewis et al. (2012), Guo et al. (2015) and Agrawal and Lee (2016) that analyze the link between sourcing and responsibility, but it incorporates some features that seem to have not been studied thoroughly within one framework. First, we analyze a dynamic stochastic environment in which actions by the supplier influence not only the current period but all future periods. Second, we link the sourcing strategy of the buyer and investment response of the supplier on responsible production. Third, we analyze the interaction between sourcing relationships and pricing policies as tools to induce responsibility and find non-trivial ways in which they interact. Finally, we explicitly delineate responsible investments from investments in quality and show that responsibility and quality are structurally different dimensions of the production process that respond to sourcing policy interventions differently.

3. Model

There are two suppliers in the market: a reliable supplier, which always complies to responsibility standards, and a generally less expensive unreliable supplier, which often does not comply. The buyer is committed to source responsibly and thus seeks to develop responsible capacity in the unreliable supplier to reduce the expected production cost[6]. If the unreliable supplier has enough responsible capacity, then the buyer will have a choice between an unreliable and reliable supplier which will drive the procurement cost down. A buyer ("he") and an unreliable supplier ("she", also "supplier" for simplicity) interact in discrete time. Each period the supplier makes a responsibility investment decision x_t. which affects her "responsibility level"[7]. Investment in period x_t has an additive impact $f(x_t)\,\rho^{y-t}$ on the responsibility level in *each* period $y \geq t$, where depreciation rate is given by $(1-\rho) \in (0;1)$. Hence the total responsibility level of period y equals

$$\rho_y = \sum_{j=-\infty}^{y} f(x_j)\rho^{y-j}$$

We also make the following technical assumptions. First, $f(\cdot)$ is a bounded twice differentiable increasing and strictly[8] concave function. Second, the costs associated with the investment x_t are incurred in period t and equal $c(x_t)$, where $c(\cdot)$ is a twice differentiable increasing strictly convex function with $c'(0) = 0$ [9]. By imposing these assumptions, we guarantee two things. First, we make sure that it is impossible to instantly bring the responsibility level to any arbitrary level. Second, we also guarantee that every additional unit of investment, made in the same period, brings less marginal value and higher marginal cost to the supplier.

Each period the buyer makes a sourcing decision – whether to source from the unreliable supplier, which depends on the commitment given to the supplier, her production cost and, most importantly, responsibility level. Over time, sourcing periods may alternate with non-sourcing periods (see Figure 1).

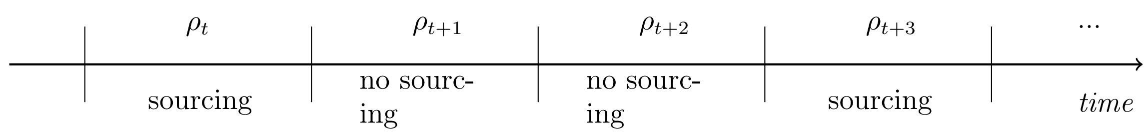

Figure 1: sourcing as a process that depends on the responsibility level.
In each period the buyer decides to source from the supplier conditional on her responsibility level ρ_t.

This policy is similar to the one used by Starbucks[10]. Overall, there are three factors that determine whether the buyer sources goods from the supplier in period t: (1) supplier's responsibility

[6] While in practice, there are more than two suppliers, to highlight the intuition, we focus our attention on two generic suppliers, which represent groups of unreliable and reliable suppliers.

[7] Indeed, responsible production is not a zero-one metric, and there is an aggregate intensity measure reflecting how responsible the production is, which we call a "responsibility level".

[8] we assume strictness to avoid trivial equalities in the results

[9] a purely technical assumption guaranteeing a non-zero investment response; alternatively, we could assume $f'(0) = \infty$

[10] "In 2011 we assessed 129 factories and found 38 factories failed our zero-tolerance standards. As a result we discontinued 26 factories as Starbucks suppliers for standards issues. We were later able to begin business with 14 of those previously dropped factories due to improved performance." (Starbucks (2013))

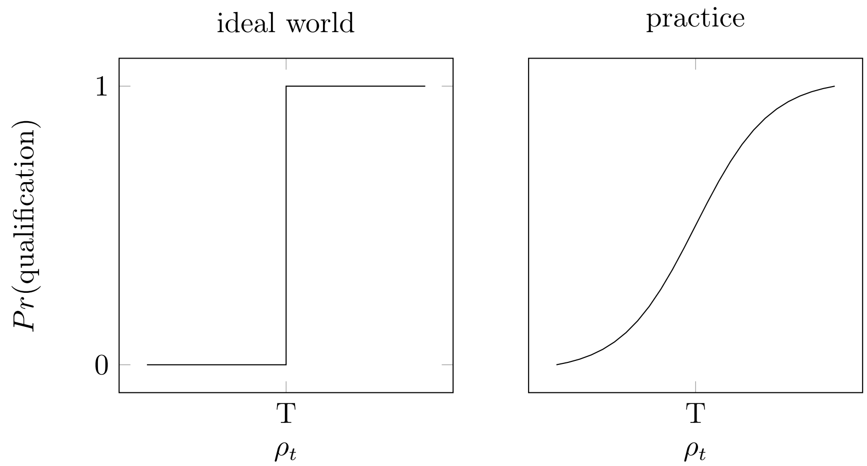

Figure 2: qualification probability as a function of responsibility level ρ_t and threshold T
In practice, the probability of the supplier passing the responsibility qualification is a smooth line rather than a step function.

qualification, (2) supplier's competitiveness, and (3) buyer's presence in the market. Each of these conditions is discussed below.

3.1. Supplier's qualification

Each period the supplier qualifies as responsible with probability ρ_t. That is, the higher the responsibility level of the supplier, the higher the probability that she will be qualified and allowed to sell goods. There are four ways to think about this assumption. First, the supplier qualifies as responsible if there are (a) no violations found by an inspection agency (buyer, NGO, government) and (b) no observable hazards happened (e.g., a fire, a building collapse, water contamination). These events are probabilistic in nature and therefore qualification happens whenever none of them occurs, probability of which is positively related to the responsibility level. Second, most inspection agencies use checklists to mark the production facility as responsible. The inspection test is "passed" provided that the number of "checks" is above a certain threshold. If the inspection is imperfect or the threshold changes w.r.t. the particular inspection team or time period, then a sourcing decision is stochastic and positively related to responsibility level (see figure 2 for an illustration). Third, if outcomes of responsible investments are stochastic (e.g., not all things go right, even if proper efforts are made), then qualification is probabilistic and monotone in responsibly level. Finally, only a share of produced goods may qualify, while another share may not qualify. Responsibility level will thus reflect the share of production which qualifies as responsible and "green-lighted" for sourcing. In any particular case at least one of the situations described above is likely to take place.

3.2. Supplier's competitiveness

As discussed before, the unreliable supplier competes on cost with the reliable supplier. A unit of good is produced by unreliable and reliable suppliers at costs c_t^1 and c_t^2 and sold by the buyer at market price p_t^m. Prices and costs evolve stochastically over time without any restrictions on their joint distribution or stationarity. In practice, goods produced by different suppliers can be sold for different prices, yet, without loss of generality, we assume a single market price p_t^m while all the price/cost differences between suppliers are captured in the respective cost processes c_t^1 and c_t^2. We also define the profit margins $\Delta_t^1 = p_t^m - c_t^1$ and $\Delta_t^2 = p_t^m - c_t^2$. Each margin can be split between the buyer and the respective supplier. If an unreliable supplier can deliver a higher margin than the reliable supplier, she is considered competitive, which increases her chances to sell goods to the buyer.

Price that unreliable supplier receives for selling one unit of good to the buyer, is denoted p_t and lies in the interval $[c_t^1, p_t^m]$. It can be also expressed as

$$p_t = c_t^1 + \gamma \left(p_t^m - c_t^1\right)$$

where $\gamma \left(p_t^m - c_t^1\right) = p_t - c_t^1$ is the price premium that the supplier receives. γ denotes the share of the supply chain margin $p_t^m - c_t^1$, that goes to the supplier. We call it the "margin split".

For illustrative purposes, the price and cost processes are represented in Figure 3.

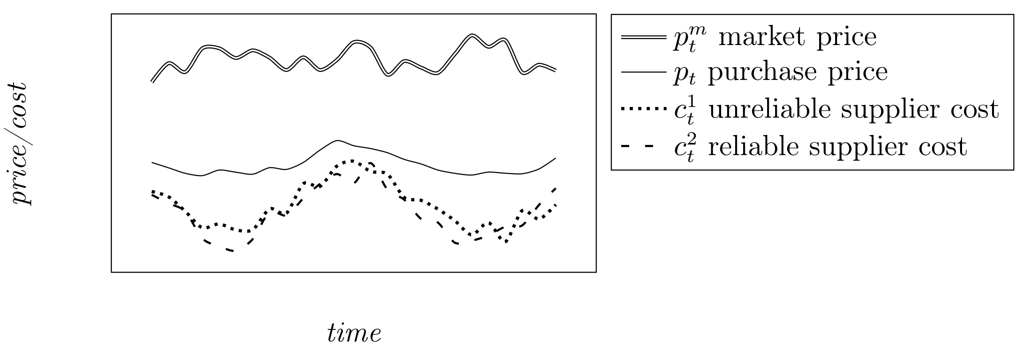

Figure 3: price and cost processes

Prices and costs evolve stochastically over time without any restrictions on their joint distribution or stationarity.

3.3. Buyer's presence

Often, a new regulation banning certain materials is introduced. Sometimes, there is a change in the political regime. Occasionally a new technology conquers the industry which makes previously procured products obsolete. At times, a buyer goes out of business. Whenever any of the situations above occurs, the buyer leaves the market, and sourcing stops. We assume that buyer leaves the market with probability $(1 - \phi) \in (0, 1)$ in each period. Therefore he is present in the market in period t with probability ϕ^t. The value that the buyer gets after this exogenous change happens is Δ_0.

3.4. Sourcing policy

Sourcing policy consists of two components. The first one is *sourcing commitment* that defines under which conditions sourcing occurs and, the second one is *pricing policy* that outlines the terms of sourcing, if it occurs.

Sourcing commitment. We consider 3 types of sourcing commitments – (1) spot market, (2) long-term relationship and (3) long-term contract. Each type of commitment defines conditions under which sourcing occurs. If the buyer sources from the suppliers in the spot market, then 3 conditions hold: (1) the supplier qualifies as responsible, (2) the buyer is operating in the market, (3) the (unreliable) supplier is competitive ($\Delta_t^1 > \Delta_t^2$). If the buyer chooses a long-term relationship, then there are only two conditions that hold: (1) the supplier qualifies, and (2) the buyer is in the market. The difference from the spot market is that now the buyer commits to source from this supplier regardless of temporary changes in her margin. Finally, under a long-term contract, even if the buyer is leaving the market, he promises to pay the termination fee equivalent to the value that the supplier is going to lose. All three sourcing commitment types can, in fact, be considered as different kinds of contracts, with different degrees of formality. Table 1 summarizes the differences between the sourcing commitments.

Relationship	**Conditions for sourcing**			**Sourcing probability**
spot market	supplier qualifies	buyer is present	$\Delta_t^1 > \Delta_t^2$	$\rho_t \phi^t \mathbb{P}\left(\Delta_t^1 > \Delta_t^2\right)$
LT relationship	supplier qualifies	buyer is present		$\rho_t \phi^t$
LT contract	supplier qualifies			ρ_t

Table 1: Sourcing commitments comparison

As a sourcing mode with the lowest commitment, spot market sourcing demands that all 3 conditions hold for a particular supplier. In particular, (1) the supplier passes the responsibility check, (2) the buyer is present in the market, and (3) the supplier's margin Δ_t^1 is higher than margin of her competitor(s) Δ_t^2. In contrast, the long-term (LT) contract demands that only one condition holds – supplier passes the responsibility check. Probability of passing the check equals the supplier's responsibility level ρ_t. Probability that the buyer is present in the market equals ϕ^t. In contrast to the long-term relaionship, the long-term contract specifies that the buyer pays the termination fee to the supplier even if he is not in the market, which, to the supplier, is equivalent to continuation of sourcing until the end of the contract.

Pricing policy. Pricing policy is a pair (γ_t, l_t) that defines the purchase price p_t and transfers l_t that depend on how the buyer and supplier split the value and costs incurred by the supply chain regardless of sourcing. For instance, who bears the costs of certification, cost of responsible investments (e.g., new management practices introduction, equipment purchases), training, or other ongoing expenses that the supply chain incurs (e.g., expenses associated with the flow of goods that do not depend on responsibility qualification), and also whether the buyer improves brand visibility of the supplier.

3.5. Timing

The timing of the model is as follows. In the beginning of time, the buyer chooses the sourcing policy, i.e. sourcing commitment and pricing policy[11]. After that, each period is characterized by the following sequence of events:

1. The buyer stays in the market with probability ϕ
2. If the buyer is in the market, supplier makes an investment decision x_t, which brings the responsibility level to $\rho_t = \sum_{j=-\infty}^{t} f(x_j)\rho^{t-j}$.
3. The supplier qualifies as responsible with probability ρ_t
4. The market price, costs of unreliable and reliable suppliers (p_t^m, c_t^1, c_t^2) realize.
5. Sourcing occurs from a reliable or unreliable supplier[12], according to the sourcing policy

4. Sourcing policy analysis

Let us analyze different sourcing policies one by one. In order, to have a benchmark, we will start with the first best.

4.1. First-best benchmark (centralized supply chain)

Imagine that the buyer and supplier operate as a centralized system. If the buyer does not source from the supplier, the supplier does not produce anything in that period and the buyer gets the outside option (shipment from the reliable supplier) valued at Δ_t^2, which becomes the system's profit. If the buyer sources from the unreliable supplier, production occurs and the system gets Δ_t^1. Sourcing from the supplier makes sense only if she qualifies as responsible and the buyer is still operating in the market. The decision of unreliable supplier on investment in responsible production (x_t^*) takes into account these contingencies and it is the decision variable that we optimize upon. The profit function of the system is given by:

[11] The buyer is assumed to be a large multinational company and the supplier is assumed to be small, thus the buyer chooses the contract terms

[12] or both, if we stick to the model interpretation, in which the responsibility level defines the proportion of total volume that goes to the unreliable supplier

$$\Pi^{\Sigma} = \sum_{t=1}^{\infty} \delta^t \left(\phi^t \left[\rho_t \mathbb{E} \max \left(\Delta_t^1, \Delta_t^2 \right) + (1-\rho_t) \mathbb{E} \Delta_t^2 - c(x_t) \right] + \phi^{t-1} (1-\phi) \Delta_t^0 \right) \rightarrow \max_{x_1, \ldots, x_\infty}$$

where $\rho_t = \sum_{j=-\infty}^{t} f(x_j) \rho^{t-j}$.

Lemma. *The first-best optimal investment level x_t^* satisfies :*

$$\frac{c'(x_t^*)}{f'(x_t^*)} = \frac{\mathbb{E}\left(\Delta_t^1 - \Delta_t^2\right)^+}{1-\delta\phi\rho} \qquad \forall t \geq 1 \tag{1}$$

(all proofs are in the Appendix)

Essentially, the centralized supply chain "cares" about the investments made by the unreliable supplier only to the extent to which unreliable supplier is more *competitive* than the reliable one. This highlights the important link between responsibility and competition. The supply chain as a profit-generating system is not concerned with responsibility per se but rather with how much more profit can responsibility generate on top of existing options. Higher levels of discount factor δ, probability of buyer's presence and investments durability are positively related to the first-best responsibility investment level. Obviously, a higher per unit contribution to the responsibility level and lower per-unit costs of investment also lead to higher first-best investment level.

The analysis is different when the buyer and supplier are independent decision-makers. Below we examine this situation under three sourcing commitments (the spot market, long-term relationship and long-term contract). We will often indicate the optimal margin split γ as the pricing policy parameter since it is a more compact representation of the purchase price $p_t = c_t + \gamma(p_t^m - c_t)$.

4.2. Spot market

Clearly, in the spot market the buyer is seeking the most profitable opportunity in every period. So he decides to source from the supplier if (1) the supplier qualifies for responsible production, (2) the buyer is still in the market, and (3) the unreliable supplier is more competitive: $\Delta_t^1 > \Delta_t^2$. As we noted above the profit margin of the supplier can be represented as share γ of the supply chain profit, which is the part of the sourcing policy. If the buyer does not source from the supplier, the supplier does not initiate production in that period and her profit is 0. Transfer payments between the parties are denoted by l.

The supplier's problem

$$\Pi_{spot}^S = \sum_{t=1}^{\infty} \delta^t \phi^t \Pi_{t,spot}^S = \sum_{t=1}^{\infty} \delta^t \phi^t \left[\rho_t \gamma \mathbb{E} \left[\Delta_t^1 I \left(\Delta_t^1 \geq \Delta_t^2 \right) \right] - c(x_t) + l \right] \rightarrow \max_{x_1, \ldots, x_\infty}$$

The buyer's problem

Since the buyer is assumed to design the contract[13] in each sourcing relationship, he is interested in maximizing the supply chain profit leaving the supplier with some reserve profit Π_0. To be precise, the problem of the buyer is given by:

$$\begin{aligned} \Pi^B_{spot} &= \Pi^\Sigma - \Pi^S_{spot} \to \max_{\gamma,l} \\ s.t.\ \Pi^S_{spot} &\geq \Pi_0 \end{aligned}$$

Equivalently the buyer is maximizing $\Pi^B_{spot} = \Pi^\Sigma - \Pi_0$, which implies that the buyer implements the first-best benchmark investment level:

$$\max_{\gamma,l} \Pi^B = \max_{x_1,\ldots,x_\infty} \Pi^\Sigma$$

The common intuition suggests that spot-market sourcing should lead to an underinvestment because it does not give enough confidence to the suppliers that their investments in responsible production would eventually pay off. Indeed, there are 3 stochastic events that may prevent the buyer from sourcing (non-qualification, non-competitiveness, buyer's market exit), and in one of them the buyer leaves the market and makes the supplier's investments unused forever. However, using the following proposition we conclude that this intuition is not always right. In fact, spot-market sourcing may lead to both underinvestment, and over-investment in the responsible production process.

Proposition 1. *The optimal spot-market contract is the vector* $\left(\gamma^*_{spot}, l^*_{t,spot}\right)$, *where* γ^*_{spot} *is the share of the supply chain profit margin that goes to the supplier, and* l^*_{spot} *is the lump-sum transfer from the buyer to supplier.*

$$\begin{aligned} \gamma^*_{spot} &= \frac{\mathbb{E}\left(\Delta^1_t - \Delta^2_t\right)^+}{\mathbb{E}\left[\Delta^1_t I\left(\Delta^1_t \geq \Delta^2_t\right)\right]} < 1 \\ l^*_{t,spot} &= \left(\Pi_0 - \sum_{i=0}^{\infty} \frac{f\left(x_{-i}\right)}{1-\rho} \left(\rho\delta\phi\right)^i \mathbb{E}\left(\Delta^1_t - \Delta^2_t\right)^+\right)(1-\delta\phi) - \left[f\left(x^*_t\right) \frac{\mathbb{E}\left(\Delta^1_t - \Delta^2_t\right)^+}{1-\delta\phi\rho} - c\left(x^*_t\right)\right] \end{aligned}$$

where x^* *is the first-best investment level, defined in 1* If the purchase price p^1_t that supplier gets per unit of good sold is set in a a way that $\gamma > \gamma^*_{spot} \in (0;1)$, then spot-market sourcing may lead to an over-investment in responsibility. This happens because the supplier does not internalize the opportunity of the system to source from elsewhere whenever it is profitable.

[13] In the context of incentivizing investments in responsible production, it seems reasonable to think of the supplier being a small firm located in a developing country and the buyer being a large multinational company (e.g., L'Oréal, Nike, Starbucks,Wal-mart) designing the contract

4.3. Long-term relationships (LTR)

In the long-term relationship case, the buyer commits to buy the goods from a particular supplier as long as the buyer is operating in the market. So, there are two conditions that guarantee sourcing decision in favor of unreliable supplier: (1) buyer is still in the market, (2) the supplier passes responsibility qualification. We start the analysis with the

Supplier's problem

$$\Pi_{LTR}^{S} = \sum_{t=1}^{\infty} \delta^t \phi^t \left[\rho_t \gamma \mathbb{E}\Delta_t^1 - c\left(x_t\right) + l\right] \to \max_{x_1,\ldots,x_\infty}$$

Under the long-term sourcing relationship, supplier has a higher marginal incentive to invest, compared to spot market sourcing: $\gamma \mathbb{E}\Delta_t^1 \geq \gamma\left(\Delta_t^1 - \Delta_t^2\right)^+$. The *buyer's problem* is very similar to the spot market case. Namely, the buyer maximizes the total profit of the supply chain and leaves the supplier with reservation profit Π_0. The optimal parameters of pricing policy can be derived in closed form.

Proposition 2. *The optimal long-term relationship contract is the vector $(\gamma_{LTR}^*, l_{LTR}^*)$, where γ_{LTR}^* is the share of the supply chain profit margin that goes to the supplier, and l_{LTR}^* is the lump-sum transfer from the buyer to supplier.*

$$\begin{aligned}
\gamma_{LTR}^* &= 1 - \frac{\mathbb{E}\Delta_t^2}{\mathbb{E}\Delta_t^1} \in (0,1) \\
l_{t,LTR}^* &= \left(\Pi_0 - \sum_{i=0}^{\infty} \frac{f\left(x_{-i}\right)}{1-\rho} \left(\rho\delta\phi\right)^i \mathbb{E}\left(\Delta_t^1 - \Delta_t^2\right)\right)\left(1-\delta\phi\right) \\
&\quad - \left[f\left(x_{t,LTR}^*\right) \frac{\mathbb{E}\Delta_t^1 - \mathbb{E}\Delta_t^2}{1-\delta\phi\rho} - c\left(x_{t,LTR}^*\right)\right]
\end{aligned}$$

where x^* is the first-best investment level, defined in equation (1) The margin split γ has a simpler form than in the spot market case. It does not rely on the joint distribution of margins Δ_t^1 and Δ_t^2 but rather on their marginal (in probabilistic sense) expectations $\mathbb{E}\Delta_t^1$ and $\mathbb{E}\Delta_t^2$.

4.4. Long-term contract (LTC)

Under the long-term contract the buyer commits to buying goods from the supplier for a fixed number of periods $T > 1$, if the supplier passes the responsibility requirements. However, if the buyer gets the signal to leave the market at some point $t < T$, which may happen with probability $\phi^{t-1}(1-\phi)$, he pays the expected remaining value, that would have been paid to the supplier if the contract was still in place, and then goes away.

Let us start the analysis with the supplier's profit function. We assume that the supplier expects the buyer to continue using the same long-term contract mechanism after the current contract expires.

$$\Pi_{LTC}^{S} = \sum_{t=1}^{T} \delta^t \left(\gamma\rho_t \mathbb{E}\left(\Delta_t^1\right) - c\left(x_t\right)\right) + \phi^T \sum_{t=T+1}^{2T} \delta^t \left(\gamma\rho_t \mathbb{E}\left(\Delta_t^1\right) - c\left(x_t\right)\right)$$

$$+\cdots+\phi^{NT}\sum_{t=NT+1}^{(N+1)T}\delta^t\left(\gamma\rho_t\mathbb{E}\left(\Delta_t^1\right)-c\left(x_t\right)\right)+\ldots$$

Now it is time to verify the intuition that long-term contracts, having a maximum sourcing guarantee, tend to be better than long-term relationships since contacts make suppliers more confident about their investments paying off.

Proposition 3. *A long-term contract with $T=\infty$ is uniquely optimal in the class of long-term contracts. The profit gained by using this contract coincides with that of the optimal long-term relationship. For that to happen, the margin split and the transfer should be set as follows:*

$$\begin{aligned}\gamma_{LTC}^* &= \frac{1-\delta\rho}{1-\delta\phi\rho}\left(1-\frac{\mathbb{E}\Delta_t^1}{\mathbb{E}\Delta_t^2}\right)\\ l_{t,LTC}^* &= \left(\Pi_0-\sum_{i=0}^{\infty}\frac{f\left(x_{-i}\right)}{1-\rho}\left(\rho\delta\phi\right)^i\mathbb{E}\left(\Delta_t^1-\Delta_t^2\right)\right)(1-\delta\phi)\\ &\quad-\left[f\left(x_{t,LTC}^*\right)\frac{\mathbb{E}\Delta_t^1-\mathbb{E}\Delta_t^2}{1-\delta\phi\rho}-c\left(x_{t,LTC}^*\right)\right]\end{aligned}$$

Corollary. *Any long-term contract with finite duration is less profitable than an optimal long-term relationship.*

The result above that the optimal long-term contract has to have an infinite duration begs for an interpretation. What does it mean that the contract duration is infinite? One way to think about it is that an infinite contract represents a long-term relationship *with* the legally promised compensation to the supplier upon its termination, equal to the expected damages to the supplier. Another interpretation is as follows. Suppose that the contract duration is finite and high enough so that it is higher than the planning horizon of the supplier, which is often the case. Then, the supplier would perceive the contract duration as infinite if the contract is renewed every period, and in each period its length is higher than the supplier's planning horizon. In other words, for the supplier with finite forecast horizon all the future beyond her horizon is discounted with factor 0; therefore, periodically renewed contracts with duration higher than the supplier's horizon are indistinguishable to her.

The pricing policy is again provided in closed form. Compared to long-term relationship, the margin split (and thus the purchase price) depends on the discount factor, probability of exiting the market and investments depreciation. In the extreme case when the buyer stays in the market with probability one, there is no difference between the long-term and contract sourcing relationships.

Now that we know the optimal pricing policies corresponding to different sourcing relationships we can compare them with each other and find the optimal one. In the next section we do precisely that by utilizing two measurable comparison criteria: responsibility performance and the buyer's profit from the sourcing relationship.

5. Key result. Optimal sourcing policy

The key result is summarized in Table 2. Namely, under the *fixed* pricing, i.e. when the buyer cannot or does not control the pricing policy, the long-term commitment yields a higher responsibility investment than the short-term commitment. However, under *flexible* pricing, when the buyer does control the prices optimally, higher responsibility performance is achieved with the short-term commitment (i.e., spot market sourcing).

	Fixed pricing	Flexible pricing
short-term commitment	Lower responsibility	**Higher** responsibility
long-term commitment	Higher responsibility	Lower responsibility

Table 2: Optimal sourcing policy

When the pricing is fixed, the common intuition holds. Namely, the more certain the supplier is about the future, the more she is willing to invest in responsible production because the future qualifications will pay off with the guarantee. The degree of certainty grows with commitment. However, surprisingly, this intuition fails when the pricing can be changed in order to maximize the buyer's profit. Short-term guarantees yield higher responsibility investment levels in that case.

The driver of the result is illustrated in figure 4. In particular, the *marginal* long-run revenue that the supply chain gets from a unit of responsible investment is different under the spot and long-term sourcing commitments:

$$\frac{\partial Rev^{\Sigma}}{\partial x_t} \propto \begin{cases} (\Delta_t^1 - \Delta_t^2)^+ & \text{if spot} \\ (\Delta_t^1 - \Delta_t^2) & \text{if long-term} \end{cases}$$

Therefore not only does the revenue curve of the spot sourcing commitment lies higher than that of the long-term commitment, but also the *slope* of that spot curve is bigger which results in a higher optimal investment level. It is true that in *any* sourcing relationship a higher investment level increases competitiveness and profitability of the supply chain due to an additional source of supply (upon compliance). However, it is the spot market sourcing in which competitiveness increases more than in other sourcing commitments, since $E\,(\Delta_t^1 - \Delta_t^2)^+ \geq E\,(\Delta_t^1 - \Delta_t^2)$.

The key intuition is as follows. High commitment allows each unit of investment to gain additional access to the market for a particular supplier, *regardless* of her competitiveness. That is, an extra unit of responsibility compliance "kills" some competition and "steals" the market share from, perhaps, a more efficient reliable supplier. As a result, a unit of responsible investment yields the higher expected profit for the supply chain in the *spot market*, which is reflected by the larger slope and, hence, the higher maximum and "argmax" of the spot market curve.

If the reliable supplier is never more profitable than the unreliable one, i.e. $\Delta_t^2 \leq \Delta_t^1$ *a.s.*, then spot and long-term sourcing commitments yield the same outcomes. If, however, the reliable supplier, at least, sometimes, performs better, i.e., $Pr\left(\Delta_t^2 \geq \Delta_t^1\right) > 0$, then the flexibility of the spot market "protects" the supply chain from losing the revenue: $Pr\left(\frac{\partial Rev_{spot}^{\Sigma}}{\partial x_t} < 0\right) = Pr\left(\left(\Delta_t^1 - \Delta_t^2\right)^+ < 0\right) = 0$, while long-term relationships or contracts do not: $Pr\left(\frac{\partial Rev_{LT}^{\Sigma}}{\partial x_t} < 0\right) = Pr\left(\left(\Delta_t^1 - \Delta_t^2\right) < 0\right) > 0$.

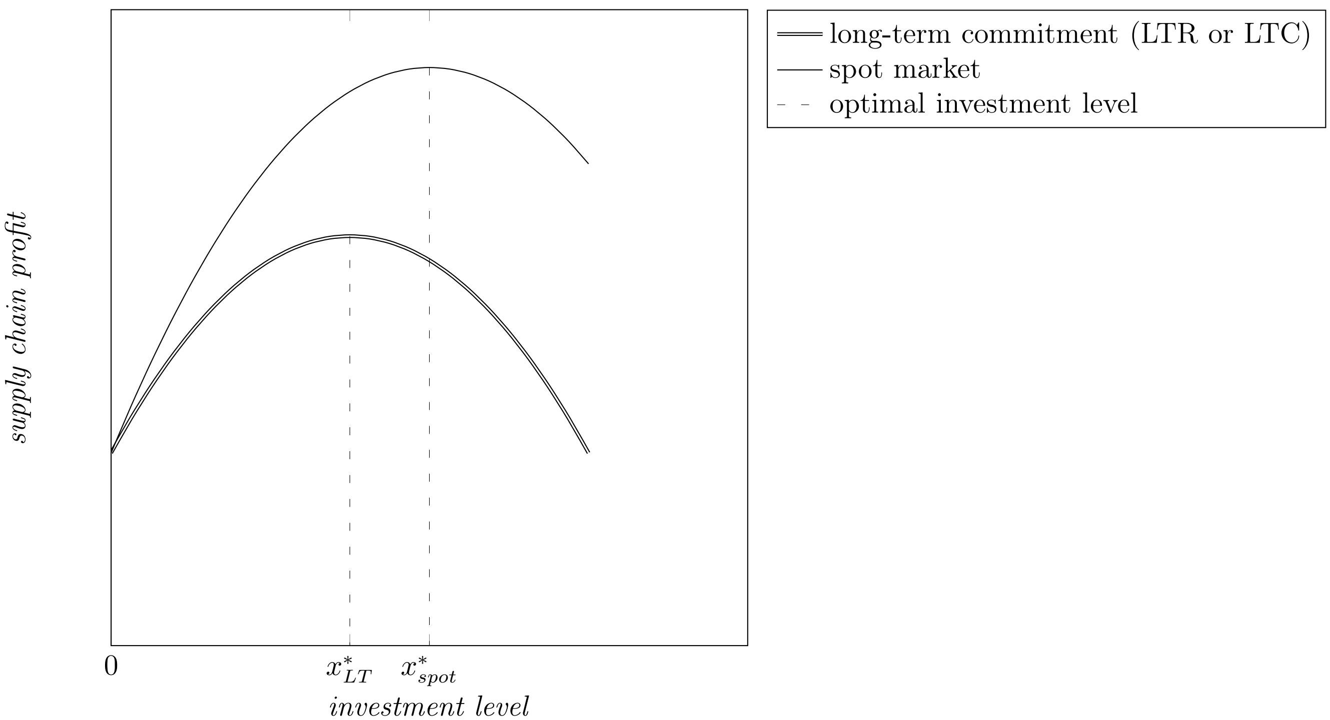

Figure 4: Supply chain profit as a function of the responsibility investment level.
The supply chain yields less profit and responsibility investment if the relationship commitment is high. High commitment allows each unit of investment to gain additional access to the market for a particular supplier, regardless of her competitiveness. That is, an extra unit of responsibility compliance "kills" some competition and "steals" the market share from, perhaps, a more efficient reliable supplier. As a result, a unit of responsible investment yields the higher expected profit for the supply chain in the spot market, which is reflected by the larger slope and, hence, the higher maximum and "argmax" of the spot market curve.

Therefore, the closer the reliable supplier profitability to that of unreliable one, and the higher the costs variability, i.e., the tougher the competition is, the more significant the difference between spot and long-term sourcing commitment becomes, since

$$E\left(\frac{\partial Rev_{spot}^{\Sigma}}{\partial x_t} - \frac{\partial Rev_{LT}^{\Sigma}}{\partial x_t}\right) \propto E\left(\Delta_t^2 - \Delta_t^1\right)^+$$

The result is formally stated using the following propositions:

Proposition 4. *If the margin split γ is fixed, the investment in responsible production is the highest under the long-term contract. It is followed by the investment level under the long-term relationship. Furthermore, spot-market sourcing leads to the lowest investment level.*

$$x_{t,LTC}(\gamma) > x_{t,LTR}(\gamma) > x_{t,spot}(\gamma) \qquad \forall t$$

Proposition 5. *If the margin split γ is flexible, the optimally-implemented spot-market sourcing leads to both higher profits, and higher investments in responsibility, in comparison to any long-term relationship or long-term contract.*

$$\Pi^*_{spot} > \Pi^*_{LTR} = \Pi^*_{LTC}$$
$$x^*_{spot} > x^*_{LTR} = x^*_{LTC}$$

Optimally-set margin splits follow the ordering:

$$\gamma^*_{spot} > \gamma^*_{LTR} > \gamma^*_{LTC}$$

On top of broadly comparing short-term and long-term commitments, the above propositions provide the comparison of a long-term relationship and a long-term contract with each other (table 3).

	Fixed pricing	Flexible pricing
long-term relationship	Lower responsibility	same responsibility if contract is auto-extended
long-term contract	Higher responsibility	same responsibility if contract is auto-extended

Table 3: long-term relationship vs long-term contract
Under fixed pricing, the general intuition is confirmed. The more certain the supplier is about the future, the more she is willing to invest in responsible production because the future qualifications will pay off with guarantee. Flexible pricing, in contrast, helps compensate higher uncertainty associated with the relationship by raising the marginal price. In addition, since the marginal increase in revenue of the buyer due to the unit change in investment, is the same under long-term relationship and contract, the optimal responsibility levels and profits are the same, provided that prices are set optimally and long-term contract duration is infinite.

The fact that the long-term contract provides the termination payment to the supplier does not help the long-term contract to outperform the long-term relationship as a sourcing relationship. In fact, the long-term contract achieves performance equivalent to the long-term relationship only if its duration is set to infinity[14]. Otherwise, if the contract duration is finite, then it necessarily yields less profit. The reason for this is that a finite contract always leads to imbalanced investment levels throughout the contract duration. The supplier starts with high investments in the beginning of the contract but finishes with lower levels towards its end. Indeed, as the supplier is getting toward the end of the contract, there is less and less time remaining in the contract, which leads

[14] as discussed in the Model section, an infinitely long contract essentially represents a long-term relationship, with legally promised compensation to the supplier upon its termination, equal to the expected sales to be lost by the supplier. Another interpretation is that this is a contract with the same termination payment but with the duration higher than the planning horizon of the supplier, and which is prolonged every period for one more period. A similar intuition is captured in the model of Guriev and Kvasov (2005).

to a reduction in investment incentives over time. Hence, it becomes impossible to reach the stable optimal investment level that appropriately balances the benefits and costs of an investment in every period. From a practical perspective, it means that signing long-term sourcing commitments which specify termination payment is not necessarily a sound strategy. Such actions will surely lead to higher investment levels. However, this may come at the expense of reduced profits. Nevertheless, if the contract duration is longer than the supplier's planning horizon, and the duration is extended in every period, then the reduced profits may be resurrected.

6. Responsibility vs. quality

6.1. Comparison of pure responsibility investments with pure quality investments

The discussion above is centered around the case of pure responsible investments. That is, when end consumers are not able to directly capture the value from responsible investments. Indeed, the direct value is frequently experienced only by *local suppliers* and their surrounding communities (e.g., cleaner air, rivers, better working conditions, no child labor), but is not directly perceived or valued by *end consumers*. Although consumers are demanding responsibly produced products and this is translated to a higher intensity of regulation, NGO pressure, and brand responsiveness w.r.t. responsibility compliance, there is no *direct* relationship between the responsibility level ρ_t and market price p_t^m. Therefore, the supply chain is concerned only about the profit margin difference $(\Delta_t^1 - \Delta_t^2)^+$ that compliance can deliver, which is based on the increased responsible supply pool and the decreased production cost associated with it, and *not* on the direct positive effect of responsible investments.

In contrast, when consumers are actually willing to internalize the value produced by investments and pay for it, incentives of the supply chain change. In that case, investments also *directly* affect the price. We call these investments "quality investments".

Let us first consider an extreme case of "pure quality" investments, in which there is no qualification or compliance, and *quality* level ρ_t increases the supply chain margin delivered by the unreliable supplier by $\alpha\rho_t$. Then we can derive the following expression for the supply chain revenue under the spot and long-term commitment sourcing:

$$E\left[Rev_t^{\Sigma}\right] \propto \begin{cases} E\left[\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right) I\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2 > 0\right)\right] + E\Delta_t^2 & \text{if spot} \\ E\left[\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)\right] + E\Delta_t^2 & \text{if long-term} \end{cases}$$

Although the spot revenue is still higher than the LTR/LTC-revenue, the *marginal* increase in revenue w.r.t. a unit of investment, is lower in the spot market. In particular it follows that (see Appendix for details):

$$\frac{\partial Rev^{\Sigma}}{\partial \rho_t} \propto \begin{cases} \alpha\left(P\left(\Delta_t^1 - \Delta_t^2 \geq -\alpha\rho\right)\right) & \text{if spot} \\ \alpha & \text{if long-term} \end{cases}$$

and thus

$$x^*_{spot} < x^*_{LT}$$

In other words, the spot market leads to lower(!) “pure quality” investment levels than long-term commitments (LTR or LTC). This means that for the “pure quality” investments case the standard intuition does hold, in contrast to the “pure responsibility” investments case. The result is illustrated in figure 5.

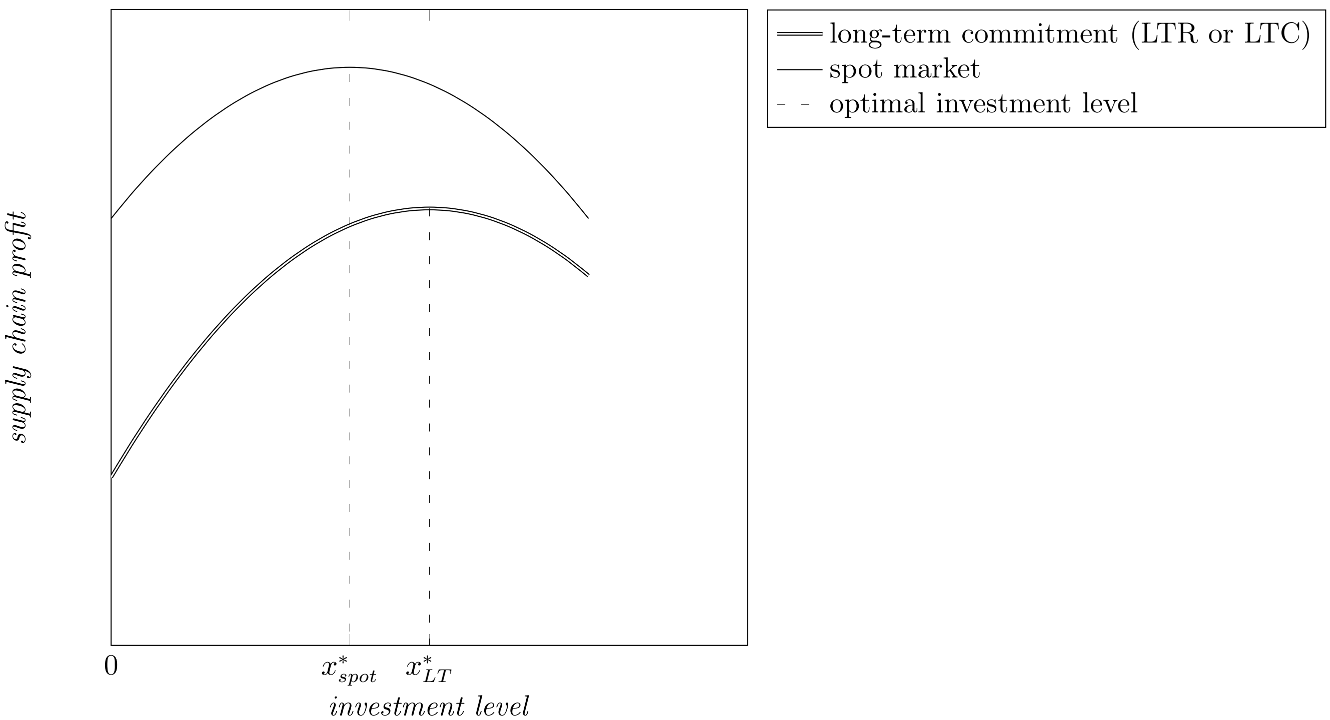

Figure 5: Supply chain profit as a function of "pure quality" investment level.
Each unit of quality investment increases the value of the product. Long-term commitment guarantees that this value will be preserved with high probability. In contrast, the spot market will ignore the created benefit, if the buyer prefers to source elsewhere. Thus the slope of the spot market curve and, hence, "argmax" are smaller.

In the “pure quality” investments case, long-term commitment-incentivized investment ρ_t increases the competitiveness of the unreliable supplier by increasing the value that she delivers to the supply chain by $\alpha\rho_t$. In the case of pure responsible investments, long-term commitment also increases the value that the unreliable supplier delivers – $\rho_t\Delta^1_t$, but, in addition, increases the opportunity costs $\rho_t\Delta^2_t$ from not being able to source from the reliable supplier due to the commitment to the unreliable supplier upon her compliance. Thus, while long-term commitments may yield *higher* product quality than the spot market, they lead to *lower* pure responsibility levels. The comparison between “pure responsibility” and “pure quality” cases are summarized in tables 4 and 5.

	(1) investments in pure responsibility	(2) investments in pure quality
Qualification probability	ρ_t	1
profit margin	Δ_t^1	$\Delta_t^1 + \alpha\rho_t$
$\frac{\partial Rev_{spot}^{\Sigma}}{\partial x} \propto$	$\mathbb{E}\left(\Delta_t^1 - \Delta_t^2\right)^+$	$\alpha Pr\left(\alpha\rho_t + \Delta_t^1 \geq \Delta_t^2\right)$
$\frac{\partial Rev_{LT}^{\Sigma}}{\partial x} \propto$	$\mathbb{E}\left(\Delta_t^1 - \Delta_t^2\right)$	α

Table 4: Pure responsibility vs pure quality investments

In the spot market, sourcing happens only if the unreliable supplier's margin Δ_t^1 is greater than the reliable supplier's margin Δ_t^2. If sourcing commitment is long-term, then sourcing happens regardless of the margin. In both cases the supplier must qualify as responsible to be considered for sourcing. Rev_{spot}^{Σ} and Rev_{LT}^{Σ} are supply chain revenues under the spot market and long-term (LT) sourcing respectively. ρ_t denotes the supplier's responsibility level in column (1) and quality level in column (2). In the case of responsibility, long-term commitment allows each unit of investment to gain additional access to the market for a particular supplier, regardless of her competitiveness. That way, an extra unit of responsibility compliance essentially "kills" some competition and "steals" the market share from, perhaps, a more efficient reliable supplier. In contrast, competition is preserved in the spot market and this creates not only more revenue, but also a stronger incentive to invest in responsibility, because, in the spot market, it does not harm competition.

On the contrary, each unit of *quality* investment increases the value of the product and, in turn, boosts revenue by $\alpha\rho_t$, which *directly* benefits the competition. In addition, long-term commitment guarantees that this increased benefit to competition will be preserved with high probability. At the same time, spot market may ignore the created benefit, if the buyer prefers to source elsewhere (i.e., when $\Delta_t^2 > \Delta_t^1$). Therefore, if pricing is set optimally, the spot market works best for incentivizing *responsibility* investments, while long-term commitments are preferred for incentivizing *quality* investments.

	Fixed pricing	Flexible pricing
Pure quality	Higher commitment →higher investment	Higher commitment →higher investment
Pure responsibility	Higher commitment →higher investment	Higher commitment →**lower** investment

Table 5: Pure responsibility vs pure quality investments

The supply chain derives benefit from responsible investments only to the extent of additional monetary profit $\left(\Delta_t^1 - \Delta_t^2\right)^+$ that they allow to bring. If the supply chain was able to capture the full benefit created by the responsible investments, i.e. $\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)^+$, then the "responsibility" problem would turn into a "quality" problem. Practically speaking, such "responsibility-to-quality reduction" can be implemented in two ways. First, by increasing awareness among consumers via branding and promotion of conscious consumption culture. This induces consumers to value "pure responsibility" efforts and ability to signal one's values by paying more for a product with the same functional characteristics. The second way is directed at shareholders and regulators. The concept of a traditional for-profit corporation can be extended to the notion of the “Benefit corporation”[15] which takes the positive impact on environment and society, along with profit maximization as its legally defined goal. In both cases “responsibility-to-quality” reduction allows to treat “pure responsible” investments as “pure quality” investments and utilize well-known quality-improvement management tools to deal with the problem.

6.2. Mixed quality and responsible investments

Now, let us combine both extreme cases – “pure responsible” investments and “pure quality” investments in one model. Let there be a responsibility-based qualification w.p. ρ_t and quality improvement value $\alpha\rho_t$ corresponding to the responsibility level ρ_t. Then, the following proposition holds.

Proposition 6. *Given optimally-set pricing, if* $E\left(\left(\Delta_t^2 - \Delta_t^1\right) I\left(\Delta_t^2 - \Delta_t^1 \geq \alpha\right)\right) \geq 2\alpha$*, that is, if the opportunity cost of sourcing from the reliable supplier is relatively higher than the quality improvement due to responsibility investments, then*

$$x^*_{xpot} \geq x^*_{LT},$$

i.e., the spot market creates higher responsibility incentives than long-term commitments.
If the responsibility qualification is abandoned and the responsibility level only affects the price of the product, then

$$x^*_{spot} \leq x^*_{LT},$$

i.e., long-term commitments create higher quality incentives than the spot market.

Corollary. *If responsibility investments are unobservable, hardly measurable or do not bring tangible benefits to consumers, i.e.,* $\alpha = 0$*, then the spot market sourcing results in the highest responsibility levels.*

There are two opposing forces at play when responsible investments are not “pure”, that is, when they also have the quality-improvement component. The first force is illustrated by the column (1) of Table 4. Investment in responsibility under the long-term commitment leads to a higher opportunity cost of not sourcing from the reliable supplier because compliance “blocks” the buyer from sourcing elsewhere, even if it is more profitable. This force favors the spot market. The second force is illustrated by the column (2) of Table 4. Quality increase will be captured with higher probability if there is a commitment to a particular supplier. That is, if there is a chance that the buyer sources elsewhere, then the investment in quality by the default supplier may not be captured by the supply chain. These two forces delineate pure responsibility and pure quality-improvement scenarios from each other. Depending on the setting, one force dominates the other.

[15] http://benefitcorp.net

7. Discussion and concluding remarks

Some aspects of the real world that have not been discussed before can also be treated within the proposed model. In particular, responsible investments that generate profit (e.g., energy efficiency solutions), may be simply introduced into the model as less costly responsible investments. Second, switching costs can also be incorporated by increasing the profit margin difference between reliable and unreliable suppliers. This would imply that it is more costly to switch to a reliable supplier if an unreliable supplier does not qualify for responsibility. Third, the sourcing decision does not have to be 0-1. Sourcing volume can be tied to the responsibility level in a continuous fashion, in the same way the expected sourcing volume is. In addition, most of the mechanisms utilized in the industry that deal with responsibility (according to (Lee et al. (2012)) – termination, reduced business, price premium, better terms and public recognition) are already treated within the model.

There are two key results derived in the paper. First, we have learnt that when the buyer sets purchase prices optimally, his higher commitment to the supplier hurts responsibility investments. In particular, the long-term commitment due its exclusivity reduces the supply-side competition. Indeed, it allows each unit of responsible investment to gain additional access to the market for a particular supplier, *regardless* of her competitiveness. That is, an extra unit of responsibility compliance "kills" competition and "steals" the market share from, perhaps, a more efficient supplier. In that regard, the spot market behaves more fairly since it uses compliance only as an entrance barrier for the cost competition which then defines the winner. Thus, the profit-maximizing supply chain encourages responsible investments *more* under the spot market relationship.

Second, we have learnt that responsibility and quality, despite sharing certain similarities, differ in profound ways. While in some cases lessons which apply to quality improvement also apply to responsibility, in others – the recommendations will be the opposite. For instance, when the buyer cannot control prices, his higher commitment to the supplier leads to higher investments in both responsibility and quality. However, when the buyer does set prices optimally, investments in quality go up with commitment, in agreement with common intuition, while responsibility investments go down. In contrast to *responsibility*, where each unit of investment benefits the supply chain *indirectly* – by increasing the responsible supply pool and thus driving the production costs down, each unit of *quality* investment increases the value (market price) of the product *directly*. Long-term commitment, in turn, guarantees that this direct benefit will be preserved with high probability. At the same time, the spot market can easily ignore this benefit, if the buyer prefers to source from a different supplier. Therefore, if prices are optimal, the spot market works best for incentivizing responsibility investments and long-term commitments are preferred for quality investments. The structural difference is driven by the fact that responsibility typically expresses itself locally, within or right next to the production facility and thus is *not* directly appreciated by the consumer, while quality propagates across the supply chain and is *directly* perceived and evaluated by the consumer. Indeed, the responsibility investments as defined in this paper are such that they are necessary for the compliance but they do not directly influence the price of the product. The price level is, instead, defined by the "zero tolerance" policies to which the ethical buyer commits (e.g., no child labor, no toxic emissions, fair employee treatment). Thus responsibility investments are profitable only because they expand the pool of the compliant supply which allows to reduce the procurement costs. This definition sharply delineates responsibility from quality investments which has not yet been done in the literature.

Importantly, we now understand that the closer the cost competition between reliable and unreliable suppliers and the higher the production cost volatility, the greater the responsibility benefit of the spot market over long-term commitments. Interestingly, we also observe that the optimal margin split that defines the optimal price, is robust to changes in investment cost and benefit functions over time, which suggests that using the margin split as the contracting parameter, and *not* the absolute price, is worthwhile.

We conclude with some practical recommendations, related to the model results. First, if the industry is in the early phase of responsibility improvement, then cost competition between reliable and unreliable suppliers, may not be high enough. In that case, long-term commitments should work well. In particular, supply chain intermediaries like Li&Fung that essentially create long-term commitment for their suppliers (Belavina and Girotra (2012)) may serve as efficient institutions that promote responsibility in such early phases of capacity development. Second, purchase prices and relationship commitment work as substitutes. Specifically, if the purchase price is low, then incentives can be amplified by increasing commitment strength (i.e. commitment duration multiplied by its credibility). For instance, if the buyer uses long-term contracts, the purchase price may be low. However, if the spot market is used, then the purchase price should be high. Third, purchase price setting is not the only component of the pricing strategy. On top of the purchase prices, transfers should be set optimally as well, which can be implemented in various ways. One way is to utilize "hybrid pricing" policy. For example, if the factory produces two types of shoes – one type for the market X (where no compliance is required) and another one – for market Y (with higher regulatory standards and necessary compliance), then the price in market X, in which shoes will be sourced regardless of responsibility qualification, can be adjusted upwards or downwards to balance transfers in the market Y. Another way to balance transfers is to share certification, audit, inspections and responsibility training costs between the buyer and supplier.

Establishing the high degree of commitment often has implicit benefits and costs, which should be considered along with the provided results. For instance, ensuring credible commitment may include costly efforts such as investing in core values and the brand linked to responsibility (e.g., Patagonia, Nike, Starbucks); using legal system enforcement, if the relationship is rooted in formal contracts; and maintaining relationships with non-profit institutions such as Fairtrade Foundation. On the other hand, keeping high commitment has its hidden benefits as well. For instance, Locke et al. (2007) find that it provides more opportunities for interaction and thereby more information about suppliers through better monitoring.

To conclude, we hope that people studying and working in supply chains could utilize both the model results and above practical considerations to make the modern economy more responsible and sustainable.

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Appendix

Proof of Lemma.

$$\Pi^{\Sigma}=\sum_{t=1}^{\infty}\delta^{t}\left(\phi^{t}\left[\rho_{t}\mathbb{E}\max\left(\Delta_{t}^{1},\Delta_{t}^{2}\right)+\left(1-\rho_{t}\right)\mathbb{E}\Delta_{t}^{2}-c\left(x_{t}\right)\right]+\phi^{t-1}\left(1-\phi\right)\Delta_{t}^{0}\right)$$

$$=\sum_{t=1}^{\infty}\delta^{t}\left(\phi^{t}\left[\left\{\sum_{j=-\infty}^{t}f\left(x_{j}\right)\rho^{t-j}\left(\mathbb{E}\max\left(\Delta_{t}^{1},\Delta_{t}^{2}\right)-\mathbb{E}\Delta_{t}^{2}\right)-c\left(x_{t}\right)\right\}+\mathbb{E}\Delta_{t}^{2}\right]+\phi^{t-1}\left(1-\phi\right)\Delta_{t}^{0}\right)$$

$$=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\left[f\left(x_{t}\right)\frac{\mathbb{E}\max\left(\Delta_{t}^{1},\Delta_{t}^{2}\right)-\mathbb{E}\Delta_{t}^{2}}{1-\delta\phi\rho}-c\left(x_{t}\right)+\mathbb{E}\Delta_{t}^{2}\right]+h\left(x_{-\infty},\ldots,x_{0}\right)$$

where $h(\cdot)$ is the function irrelevant to the decision on current and future investments. FOC for the supplier's investment in responsible production:

$$\frac{c'\left(x_{t}^{*}\right)}{f'\left(x_{t}^{*}\right)}=\frac{\mathbb{E}\max\left(\Delta_{t}^{1},\Delta_{t}^{2}\right)-\mathbb{E}\Delta_{t}^{2}}{1-\delta\phi\rho}\qquad\forall t\geq1\tag{2}$$

Proof of existence and uniqueness of the investment response is as follows. Note that $g\left(x\right)\triangleq\frac{c'(x)}{f'(x)}$ is a strictly increasing function since $\left(\frac{c'(x)}{f'(x)}\right)'=\frac{c''(x)f'(x)-f''(x)c'(x)}{(f'(x))^{2}}>0$ which is due to convexity/concavity assumptions about functions $c\left(\cdot\right)$ and $f\left(\cdot\right)$. And since $f\left(\cdot\right)\in C_{2}$ is also bounded, then $f'\left(\infty\right)=0$. Since we also know that $c'\left(0\right)=0$, then $g\left[\left[0;\infty\right)\right]=\left[0;\infty\right)$. Due to smoothness of $c\left(\cdot\right)$ and $f\left(\cdot\right),g\left(\cdot\right)$ are continuous, therefore the investment response x_{t}^{*} exists. Since also $g\left(\cdot\right)$ is strictly increasing, x_{t}^{*} is unique. We are using this result in most of the propositions below.

Proof of Proposition 1.

$$\begin{aligned}\Pi_{spot}^{S}&=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\Pi_{t,spot}^{S}=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\left[\rho_{t}\gamma\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]-c\left(x_{t}\right)+l\right]\\&=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\left[\gamma\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]\sum_{j=-\infty}^{t}f\left(x_{j}\right)\rho^{t-j}-c\left(x_{t}\right)+l\right]\\&=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\left[f\left(x_{t}\right)\frac{\gamma\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]}{1-\delta\phi\rho}-c\left(x_{t}\right)+l\right]\\&+\sum_{i=0}^{\infty}\frac{f\left(x_{-i}\right)}{1-\rho}\left(\rho\delta\phi\right)^{i}\gamma\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]\to\max_{x_{1},\ldots,x_{\infty}}\end{aligned}$$

FOC:

$$\frac{c'\left(x_{t}\right)}{f'\left(x_{t}\right)}=\frac{\gamma\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]}{1-\delta\phi\rho}\qquad\forall t\geq1\,\frac{\mathbb{E}\left(\Delta_{t}^{1}-\Delta_{t}^{2}\right)^{+}}{\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]}=\frac{\mathbb{E}\left[\left(\Delta_{t}^{1}-\Delta_{t}^{2}\right)I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]}{\mathbb{E}\left[\Delta_{t}^{1}I\left(\Delta_{t}^{1}\geq\Delta_{t}^{2}\right)\right]}\leq1$$

Proof of Proposition 2. $\Pi_{LTR}^{S}=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\left[\rho_{t}\gamma\mathbb{E}\Delta_{t}^{1}-c\left(x_{t}\right)+l\right]=\sum_{t=1}^{\infty}\delta^{t}\phi^{t}\left[f\left(x_{t}\right)\frac{\gamma\mathbb{E}\Delta_{t}^{1}}{1-\delta\phi\rho}-c\left(x_{t}\right)-c_{0}+l\right]+\sum_{i=0}^{\infty}\frac{f(x_{-i})}{1-\rho}\left(\rho\delta\phi\right)^{i}\gamma\mathbb{E}\left[\Delta_{t}^{1}\right]\to\max_{x_{1},\ldots,x_{\infty}}$

FOC:

$\frac{c'(x_{t})}{f'(x_{t})}=\frac{\gamma\mathbb{E}\Delta_{t}^{1}}{1-\delta\phi\rho}\qquad\forall t\geq1$

Notice that the long-term relationship arrangement, from the centralized supply chain perspective, is less profitable than the "first-best". This is due to the forgone flexibility of choosing the best supplier in every period. So, instead of the "first-best", i.e. without any restrictions on the sourcing mode, the system would now get the "second-best":

$\Pi^*_{LTR} = \max_{x_0,\ldots,x_\infty} \Pi^{\Sigma}_{LTR} = \max_{x_0,\ldots,x_\infty} \sum_{t=0}^{\infty} \delta^t \phi^t \left[f(x_t) \frac{\mathbb{E}\Delta^1_t - \mathbb{E}\Delta^2_t}{1-\delta\phi\rho} - c(x_t) + \mathbb{E}\Delta^2_t \right] + \sum_{i=0}^{\infty} \frac{f(x_{-i})}{1-\rho} (\rho\delta\phi)^i \gamma \mathbb{E}\left[\Delta^1_t\right]$

FOC:

$\frac{c'\left(x^*_{t,LTR}\right)}{f'\left(x^*_{t,LTR}\right)} = \frac{\mathbb{E}\Delta^1_t - \mathbb{E}\Delta^2_t}{1-\delta\phi\rho}$

The buyer's problem is given by

$$\Pi^B_{LTR} = \Pi^{\Sigma}_{LTR} - \Pi^S_{LTR} \to \max_{\gamma,l}$$
$$s.t.\ \Pi^S_{LTR} \geq \Pi_0$$

Equivalently the buyer is maximizing $\Pi^B_{LTR} = \Pi^{\Sigma}_{LTR} - \Pi_0 \to \max_{\gamma,l}$

Therefore, the FOC for the buyer's problem coincides with the FOC for the "second best" derived above.

Proof of Proposition 3.

$$\begin{aligned}\Pi^S_{LTC} = {} & h_{LTC}(x_{-\infty},\ldots,x_0) + \sum_{t=1}^{T} \delta^t \left(\gamma\rho_t \mathbb{E}\left(\Delta^1_t\right) - c(x_t)\right) + \phi^T \sum_{t=T+1}^{2T} \delta^t \left(\gamma\rho_t \mathbb{E}\left(\Delta^1_t\right) - c(x_t)\right) \\ & + \cdots + \phi^{NT} \sum_{t=NT+1}^{(N+1)T} \delta^t \left(\gamma\rho_t \mathbb{E}\left(\Delta^1_t\right) - c(x_t)\right) + \ldots\end{aligned}$$

where $h_{LTC}(\cdot)$ is the function irrelevant to the decision on current and future investments.

To save space, we will write out the part of the profit function depending on investments within one contract period, i.e. on $x_t,\ t = 1,\ldots,T$. Due to separability, other terms and their FOC's can be analyzed analogously.

$$\begin{aligned}& \sum_{t=1}^{T} \delta^t \left[\gamma \mathbb{E}\left(\Delta^1_t\right) f(x_t) \sum_{j=t}^{T} (\delta\rho)^{j-t} - c(x_t)\right] + \\ & + \sum_{t=1}^{T} \delta^t \left[\gamma \mathbb{E}\left(\Delta^1_t\right) f(x_t) \left(\phi^{T+1-t} \sum_{j=T+1}^{2T} (\delta\rho)^{j-t} + \cdots + \phi^{NT+1-t} \sum_{j=NT+1}^{(N+1)T} (\delta\rho)^{j-t} + \ldots\right)\right] = \\ & \sum_{t=1}^{T} \delta^t \left(\gamma \mathbb{E}\left(\Delta^1_t\right) f(x_t) \frac{1-(\delta\rho)^{T-t+1}}{1-\delta\rho} - c(x_t)\right) + \\ & + \sum_{t=1}^{T} \delta^t \left[\gamma \mathbb{E}\left(\Delta^1_t\right) f(x_t) \left((\phi\delta\rho)^{T-t+1} \frac{1-(\delta\rho)^T}{1-\delta\rho} + \cdots + (\phi\delta\rho)^{NT-t+1} \frac{1-(\delta\rho)^T}{1-\delta\rho} + \ldots\right)\right] = \\ & = \sum_{t=1}^{\infty} \delta^t \left(\gamma \mathbb{E}\left(\Delta^1_t\right) \frac{f(x_t)}{1-\delta\rho} \left[1-(\delta\rho)^{T-t+1} + \left(1-(\delta\rho)^T\right) \frac{(\phi\delta\rho)^{T-t+1}}{1-(\phi\delta\rho)^T}\right] - c(x_t)\right)\end{aligned}$$

FOC:

$$\frac{c'(x_{t,LTC})}{f'(x_{t,LTC})} = \frac{\gamma \mathbb{E}\left(\Delta^1_t\right)}{1-\delta\rho} \left[1-(\delta\rho)^{T-t+1} + \left(1-(\delta\rho)^T\right) \frac{(\phi\delta\rho)^{T-t+1}}{1-(\phi\delta\rho)^T}\right] \qquad \forall t = 1,\ldots,T \tag{3}$$

Let us look at the second-best problem for the long-term contracts. For the period t in and before which the decision to leave the market has not arrived, the profit function coincides with the one calculated for long-term relationships:

$$\Pi_{LTC} = \Pi_{LTR} = \sum_{t=0}^{\infty} \delta^t \phi^t \left[f(x_t) \frac{\mathbb{E}\Delta_t^1 - \mathbb{E}\Delta_t^2}{1-\delta\phi\rho} - c(x_t) + \mathbb{E}\Delta_t^2 \right] + \sum_{i=0}^{\infty} \frac{f(x_{-i})}{1-\rho} (\rho\delta\phi)^i \gamma \mathbb{E}\left[\Delta_t^1 I\left(\Delta_t^1 \geq \Delta_t^2\right)\right]$$

Please note, that the termination fees are not present in the profit function because it is an internal transfer between the buyer and a supplier which cancels out while computing the supply chain surplus.

So the first-order condition is already known:

$$\frac{c'\left(x^*_{t,LTC}\right)}{f'\left(x^*_{t,LTC}\right)} = \frac{c'\left(x^*_{t,LTR}\right)}{f'\left(x^*_{t,LTR}\right)} = \frac{\mathbb{E}\Delta_t^1 - \mathbb{E}\Delta_t^2}{1-\delta\phi\rho} \tag{4}$$

On inefficiency of finite duration contracts:

If $2 \leq T < \infty$:

It is easy to see from (3) that under the contract with finite duration the investment level chosen by the supplier is not constant during the contract regardless of the chosen contract parameters. However, the second-best level is constant (equation 4). Therefore, if the contract duration is T such that $2 \leq T < \infty$, then the supplier's investment level is in disagreement with the second-best level in at least $(T-1)$ periods.

If $T = \infty$:

$$\frac{c'\left(x_{t,LTC}\right)}{f'\left(x_{t,LTC}\right)} = \frac{\gamma \mathbb{E}\left(\Delta_t^1\right)}{1-\delta\rho} \qquad \forall t$$

Comparison with (4), yields the optimal margin split. The value of the transfer is computed by equating the profit of the buyer to its reservation profit.

Proof of Proposition 4. First, let us remind ourselves that $g(x) \triangleq \frac{c'(x)}{f'(x)}$ is a strictly increasing function (see the proof of Lemma). Then, we take first order conditions for the supplier's response under each sourcing commitment and order their right-hand-sides taking into account that $\mathbb{P}\left(\Delta_t^1 \in (0;\Delta_t^2)\right) > 0$ and $\Delta_t^1, \Delta_t^2 \geq 0$ *a.s.*:

$$\frac{\gamma \mathbb{E}\left[\Delta_t^1 I\left(\Delta_t^1 \geq \Delta_t^2\right)\right]}{1-\delta\phi\rho} < \frac{\gamma \mathbb{E}\Delta_t^1}{1-\delta\phi\rho} =$$

$$= \gamma \mathbb{E}\Delta_t^1 \left(\sum_{j=t}^{\infty} (\delta\rho\phi)^{j-t} \right) <$$

$$\gamma \mathbb{E}\Delta_t^1 \left(\sum_{j=t}^{T} (\delta\rho)^{j-t} + \phi^{T+1-t} \sum_{j=T+1}^{2T} (\delta\rho)^{j-t} + \dots + \phi^{NT+1-t} \sum_{j=NT+1}^{(N+1)T} (\delta\rho)^{j-t} + \dots \right)$$

The statement of the proposition immediately follows.

Proof of Proposition 5. (1) comparing investment levels. Equating the derivatives of the total supply chain profit to 0, we get

$$\frac{c'\left(x^*_{t,spot}\right)}{f'\left(x^*_{t,spot}\right)} = \frac{\mathbb{E}\left(\Delta_t^1 - \Delta_t^2\right)^+}{1-\delta\phi\rho} \frac{c'\left(x^*_{t,LTR}\right)}{f'\left(x^*_{t,LTR}\right)} = \frac{c'\left(x^*_{t,LTC}\right)}{f'\left(x^*_{t,LTC}\right)} = \frac{\mathbb{E}\left(\Delta_t^1 - \Delta_t^2\right)}{1-\delta\rho}$$

The ordering for optimal investment responses follows from the fact that $g(x) \triangleq \frac{c'(x)}{f'(x)}$ is a strictly increasing function (see the proof of Lemma).

(2) comparing optimal margin splits. Since $\mathbb{P}(\Delta_t^1 \in (0;\Delta_t^2)) > 0$ and $\Delta_t^1, \Delta_t^2 \geq 0$ $a.s.$, then $\frac{\gamma^*_{LTR}}{\gamma^*_{spot}} = \frac{\mathbb{E}(\Delta_t^1-\Delta_t^2)}{\mathbb{E}(\Delta_t^1-\Delta_t^2)^+}\frac{\mathbb{E}\left[\Delta_t^1 I\left(\Delta_t^1 \geq \Delta_t^2\right)\right]}{\mathbb{E}\Delta_t^1} < 1$

$$\frac{\gamma_{*LTR}}{\gamma^*_{LTC}} = \frac{1-\delta\phi\rho}{1-\delta\rho} > 1$$

(3) comparing optimal profits. Centralized chain profits satisfy $\Pi_{spot}\left(\{x_t\}_{-\infty}^{\infty}\right) > \Pi_{LTR}\left(\{x_t\}_{-\infty}^{\infty}\right) = \Pi_{LTC}\left(\{x_t\}_{-\infty}^{\infty}\right)$. Since the spot market can, in fact, fully coordinate the chain (see the proof of Proposition 1), and since a long-term contract with $T=\infty$ and a long-term relationship achieve the second-best (Proposition 3), the above inequalities hold for the optimal profits as well: $\Pi^*_{spot}\left(\{x_t\}_{-\infty}^{\infty}\right) > \Pi^*_{LTR}\left(\{x_t\}_{-\infty}^{\infty}\right) = \Pi^*_{LTC}\left(\{x_t\}_{-\infty}^{\infty}\right)$.

Pure quality investments analysis. Since the supply chain revenue functions under spot market and long-term commitment (LTR or LTC) can be represented as

$$E\left[Rev_t^{\Sigma}\right] \propto \begin{cases} E\left[\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right) I\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2 > 0\right)\right] & \text{if spot} \\ E\left[\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)\right] & \text{if LTR or LTC} \end{cases}$$

Therefore, under the spot market, using Leibniz rule,

$$\begin{aligned}
\frac{\partial Rev^{\Sigma}_{t,spot}}{\partial\rho_t} &\propto \frac{\partial}{\partial\rho_t}\int_{-\alpha\rho_t}^{\infty}\left(x+\alpha\rho_t\right)dF\left(x\right) \\
&= \frac{\partial}{\partial\rho_t}\left(\alpha\rho_t\int_{-\alpha\rho_t}^{\infty}dF\left(x\right) + \int_{-\alpha\rho_t}^{\infty}xf\left(x\right)dx\right) \\
&= \frac{\partial}{\partial\rho_t}\left(\alpha\rho_t\left(1-F\left(-\alpha\rho_t\right)\right) + \int_{-\alpha\rho_t}^{\infty}xf\left(x\right)dx\right) \\
&= \alpha\left(1-F\left(-\alpha\rho_t\right)\right) + \alpha^2\rho_t f\left(\alpha\rho\right) - \alpha^2\rho_t f\left(\alpha\rho_t\right) \\
&= \alpha\left(1-F\left(-\alpha\rho_t\right)\right) = \alpha P\left(\Delta_t^1 + \alpha\rho_t - \Delta_t^2 \geq 0\right)
\end{aligned}$$

where $f(\cdot)$ and $F(\cdot)$ are pdf and cdf of random variable $\Delta_t^1 - \Delta_t^2$.

Under the long-term commitment $\frac{\partial Rev^{\Sigma}_{t,LT}}{\partial\rho_t} \propto \frac{\partial}{\partial\rho_t}\left(\alpha\rho_t + E\left(\Delta_t^1 - \Delta_t^2\right)\right) = \alpha$

Thus

$$\frac{\partial Rev^{\Sigma}}{\partial\rho_t} \propto \begin{cases} \alpha\left(P\left(\Delta_t^1 - \Delta_t^2 \geq -\alpha\rho_t\right)\right) & \text{if spot} \\ \alpha & \text{if LTR or LTC} \end{cases}$$

Then $\alpha\left(P\left(\Delta_t^1 - \Delta_t^2 \geq -\alpha\rho_t\right)\right) \leq \alpha$

Thus, since the costs of responsible investments in both cases are the same, due to Topkis theorem $x^*_{LT} \geq x^*_{spot}$.

Proof of Proposition 6. The supply chain revenue functions under spot market and long-term commitment (LTR or LTC) can be represented as

$$E\left[Rev_t^{\Sigma}\right] \propto \begin{cases} \rho_t E\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)^+ + E\Delta_t^2 & \text{if spot} \\ \rho_t E\left[\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)\right] + E\Delta_t^2 & \text{if LTR or LTC} \end{cases}$$

Therefore, under spot market, utilizing the derivative computation made above

$$\begin{aligned}
\frac{\partial Rev^{\Sigma}_{t,spot}}{\partial\rho_t} &\propto E\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)^+ + \frac{\partial}{\partial\rho_t}\int_{-\alpha\rho_t}^{\infty}\left(x+\alpha\rho_t\right)dF\left(x\right) \\
&= E\left(\alpha\rho_t + \Delta_t^1 - \Delta_t^2\right)^+ + \alpha P\left(\Delta_t^1 - \Delta_t^2 \geq -\alpha\rho_t\right)
\end{aligned}$$

Under long-term commitment: $\frac{\partial Rev^{\Sigma}_{t,LT}}{\partial \rho_t} \propto E\left(\alpha\rho_t + \Delta^1_t - \Delta^2_t\right) + \alpha$

Therefore

$$\begin{aligned}\frac{\partial Rev^{\Sigma}_{t,spot}}{\partial \rho_t} - \frac{\partial Rev^{\Sigma}_{t,LT}}{\partial \rho_t} &\propto E\left(\Delta^2_t - \left(\Delta^1_t + \alpha\rho_t\right)\right)^+ - \alpha P\left(\Delta^2_t \geq \Delta^1_t + \alpha\rho_t\right) \\ &= E\left[\left(\Delta^2_t - \left(\Delta^1_t + \alpha\rho_t\right)\right) I\left(\Delta^2_t \geq \Delta^1_t + \alpha\rho_t\right) - \alpha I\left(\Delta^2_t \geq \Delta^1_t + \alpha\rho_t\right)\right] \\ &= E\left[\left(\Delta^2_t - \Delta^1_t - \left(1+\rho_t\right)\alpha\right) I\left(\Delta^2_t \geq \Delta^1_t + \alpha\rho_t\right)\right]\end{aligned}$$

Clearly, if $\alpha = 0$, then

$$\frac{\partial Rev^{\Sigma}_{t,spot}}{\partial \rho_t} - \frac{\partial Rev^{\Sigma}_{t,LT}}{\partial \rho_t} \propto E\left(\Delta^2_t - \Delta^1_t\right)^+ \geq 0$$

If also $\rho_t > 0$ and α is high enough that $\Delta^1_t + \alpha\rho_t \geq \Delta^2_t$ $a.s.$, then $\frac{\partial Rev^{\Sigma}_{t,spot}}{\partial \rho_t} = \frac{\partial Rev^{\Sigma}_{t,LT}}{\partial \rho_t}$.

Finally, since $E\left[\left(\Delta^2_t - \Delta^1_t - \left(1+\rho_t\right)\alpha\right) I\left(\Delta^2_t \geq \Delta^1_t + \alpha\rho_t\right)\right] = \int_{\alpha\rho_t}^{\infty} x f(x)\,dx - \left(1+\rho_t\right)\alpha\left(1 - F(\alpha\rho)\right)$, where $f(\cdot)$ and $F(\cdot)$ are the pdf and cdf of random the variable $\Delta^2_t - \Delta^1_t$, and for any fixed α, $\rho \in (0,1) : \int_{\alpha\rho_t}^{\infty} x f(x)\,dx \geq \int_{\alpha}^{\infty} x f(x)\,dx$ as well as $\left(1+\rho_t\right)\alpha\left(1 - F(\alpha\rho)\right) \leq 2\alpha$, then as long as $E\left(\left(\Delta^2_t - \Delta^1_t\right) I\left(\Delta^2_t - \Delta^1_t \geq \alpha\right)\right) \geq 2\alpha$, it holds that $\frac{\partial Rev^{\Sigma}_{t,spot}}{\partial \rho_t} \geq \frac{\partial Rev^{\Sigma}_{t,LT}}{\partial \rho_t}$. That is, if the opportunity cost of sourcing from the reliable supplier is relatively higher than the quality improvement due to responsibility investments, the spot market creates higher responsibility incentives than long-term commitments, if pricing is set properly.