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Dynamic Relational Contracts for Quality Enforcement in Supply Chains

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Abstract. We model the interaction of a single buyer with a single supplier within a market in a developing country with homogeneous local suppliers and homogeneous buyers from developed nations. The buyer sources a product from a supplier and then inspects and sells it on the market, subject to quality standards such as regulations about chemical content. Suppliers decide how much effort to exert to ensure compliance with quality standards. Buyers are assumed to comply with contracts because they are based in countries with strong legal systems. We assume that legal enforcement of the supplier's contractual obligations is not possible. We model the interaction between buyer and supplier as a repeated game in which the partnership can be terminated by the buyer if the supplier refuses to pay penalties for quality violations. After termination, the buyer and supplier each search for a new business partner. We model the interaction between buyer and supplier using relational contacts in which penalties for quality failures are set so that the supplier voluntarily pays them. We show that optimal relational contracts have dynamic form in this setting because the value of the outside option available to the parties, if the relationship is terminated, is determined by the contract terms. We characterize the properties of the optimal dynamic equilibria and analyze the use of third-party quality certifications within this framework.

Keywords: supply chain • sustainability • quality • relational contracts

1. Introduction

On November 24, 2012, more than 100 people were killed in a Tazreen garment factory fire in Bangladesh. Investigations found that conditions in the factory were unsafe and that the factory was producing garments for a local supplier to several well-known Western retailers including Walmart and Sears. Both Walmart and Sears denied knowing that this factory was being used by its suppliers. In fact, Walmart asserts that it delisted the Tazreen factory because of safety issues. However, one of Walmart’s suppliers placed an order with a third party that, facing a capacity shortage, outsourced some of the order to the company operating the Tazreen factory that burned down. Walmart subsequently fired its supplier. The above summary of the incident is based upon reporting in the Wall Street Journal and the New York Times (Chiu and Lahiri 2012, Yardley 2012, Zain et al. 2012).

This tragic case illustrates the challenges firms face in maintaining standards in labor practices in their supply chains. But the same issues exist, to varying degrees, for firms trying to maintain any form of manufacturing quality standards. These standards could be related to the functional performance of the products, to regulatory compliance, or to sustainability goals, among others. In the following, we refer to firms trying to maintain quality standards in their supply chains as buyers, where these could be original equipment manufacturers, retailers, or brands.

The example of Walmart and the garments sourced in Bangladesh shows how complex a firm’s supply chain can be and how difficult it can be to know who is producing the firm’s product and how it is being produced. Both the size and the multitier structure of the supply chain complicate quality assurance. We see that disqualifying a supplier is a tool in a buyer’s arsenal, while at the same time we see that a disqualified supplier (e.g., the Tazreen factory) will not necessarily lack for business. We also see that buyers do inspect their suppliers, but this oversight is costly and incomplete. Another dimension to this story is that buyers like Walmart know that when sourcing to poor, developing nations they are seeking low costs that are achieved by lower wages and poorer safety conditions. While the buyers may do more auditing of suppliers and make investments in improving standards, they are not abandoning Bangladesh. We point this out to indicate that buyers do have constraints on their choice of suppliers in the sense that economic factors force them to operate in specific countries.
For the purposes of this paper, we focus on environmental standards regarding the chemical content of products to make the discussion more concrete but also because it is an especially challenging domain. Environmental regulations vary greatly across countries and are in a state of flux. With chemical content, it can be harder to observe quality failures than in the case of product function.

When hazardous chemicals are detected in a product that has reached consumers, the cost to a firm can be significant. After a melamine contamination in 2008, Chinese milk products were recalled globally (New York Times 2011). When Yili, a major dairy firm in China, recalled some of its baby formula products because of mercury contamination in 2012, its share prices immediately fell approximately 10% (BBC News 2012). Other examples are the recalls of toxic toys and children’s products in 2007 and 2010. In 2007, the U.S. Consumer Product Safety Commission recalled over 17 million toys in violation of the lead paint standard, including two million toys of Mattel. Product safety and health issues contributed to the 2008 financial crisis that caused 4,222 out of 8,610 toy factories in China to be closed (Macartney 2009). In 2010, McDonald’s recalled 12 million Shrek drinking glasses with cadmium contaminated paint. Before the recall, about 7.5 million glasses had been sold. McDonald’s paid $3.00 for every returned item, while the price for a glass was $2.49 without a food purchase and only $1.99 with one (Neuman 2010). In these cases the buyer bore the direct costs in terms of remediation and reputation effects.

In the electronics industry as of July 2006, the European Union (EU) (Directive 2002/95/EC1) requires a wide range of products to be Restriction of Hazardous Substances (RoHS) compliant. This means that the amount of the six substances found in electronics products (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers) is severely restricted. Failure to comply with RoHS regulations can lead to a product being banned from sale in the EU as well as significant fines. Complying with RoHS is challenging for a large company like Hewlett-Packard, which operates in more than 170 countries and has over 600 suppliers (Becker et al. 2010).

In 2013, the nonprofit organization, the Center for Environmental Health (CEH), discovered that major U.S. retailers were selling personal care products containing cocamide diethanolamine (CDEA), a chemical declared as a known carcinogen in California under Proposition 65. Among the retailers who did not label their products for hazardous chemical content were Babies R Us, CVS, J. C. Penney, Kohl’s, Kmart, Macy’s, Marshalls, Rite Aid, Sears, Target, Ulta, Walgreens, and Walmart. The CEH tested 98 shampoos, soaps, and other personal care products and showed that many of the products contained more than 1% of CDEA, while one shampoo had more than 20%. In August 2013, the environmental watchdog filed a lawsuit against four companies including Walgreens, asking the court to fine the companies $2,500 a day per violation. Additionally, the CEH sent legal notices to more than 100 other manufacturers and retailers indicating that they were in violation of state law (Environment News Service 2013).

To prevent hazardous chemical content in their products, buyers employ several mechanisms including financial incentives to encourage better quality and compliance, financial penalties for quality failures, inspections and testing, and product redesign. For instance, the CEH says that during its 17-year work with manufacturers and retailers, in 95% of cases, it has won legally binding agreements requiring product reformulation (Radcliffe 2013).

Some authors advise reducing the cost pressure on suppliers (Plambeck et al. 2011, Teagarden 2009). This approach has its limitations because instead of stimulating quality improvement, higher payments may encourage a supplier to collect higher profit in the short run by reducing its own quality assurance efforts. Buyers who use financial penalties for quality failures also face challenges because, as Midler (2007) documents, in developing countries such penalties may be difficult to enforce. Reformulating products is not always feasible and also can require intensive coordination with the suppliers. See Becker (2009b, c) for a description of S.C. Johnson and Hewlett-Packard’s efforts in this regard. Buyers also invest in costly inspection efforts to ensure that products with prohibited and/or hazardous chemicals do not reach end consumers. For example, after the recalls in 2007, Mattel developed the redundant four-level inspection system, although Mattel’s CEO admits this system does not guarantee absolute safety (Lyles 2008). See also Becker (2009a) for a description of Nike’s inspection efforts. If a buyer detects compliance failures at its supplier, it is unclear what actions the buyer should take. One option that is always available is to terminate the relationship with the supplier; yet the buyer will still need to find a supplier, with no guarantee that the new supplier will perform better.

With these observations in mind, in this paper we analyze quality control and contracting in a supply chain in which there is an asymmetric ability to enforce contract terms. We assume that the buyers are well-established firms with strong reputations for adhering to contracts. We also assume that they trade with smaller suppliers that operate in countries in which the legal environment is such that it is difficult to enforce the suppliers’ compliance with contract terms. Thus, it is necessary to consider supplier termination as an option in the model. Including termination gives a
richer and more realistic framework for understanding how a buyer can maintain quality standards in a supply chain.

We make the following contributions. First, we formulate a new model of buyer-supplier contracting for quality in an environment in which the buyer can commit to contract terms but the supplier cannot; when contracts are terminated, the parties must engage in a costly search for new partners. Second, we show that there are conditions when dynamic contracts are optimal even though the problem setting is static. Third, we show that holding the supplier’s profit low (zero) at the start of the relationship and postponing the supplier’s opportunity for profit to later periods, while steadily ramping up quality expectations, increases the buyer’s leverage and improves quality. This provides the buyer with a mechanism for artificially increasing the supplier’s termination costs. Fourth, we extend our model to account for third-party quality-compliance certification and show that certification can hurt the buyer’s ability to design optimal dynamic contracts because the certification is inflexible. Certification can essentially move the buyer to a more mature state of the relationship prematurely and undermine the buyer’s ability to increase the supplier’s termination costs.

In Section 2 we review the related literature. In Section 3 we present the main model formulation and analyze enforceable and nonenforceable contracts. In Section 4 we conduct numerical sensitivity analyses to explore the factors that drive contract performance. In Section 5 we extend our model and analyze situations in which third-party quality-compliance certification is available. We investigate the factors that determine if such certifications have a potential benefit to the buyer. We conclude in Section 6.

2. Literature Review

Our work belongs to three research areas: quality enforcement in supply chains, dynamic moral hazard, and relational contracts. The first stream of the related literature studies court enforceable quality control contracts and considers different tools to ensure quality. Reyniers and Tapiero (1995) study a contract including price rebates and after-sales warranty costs. If poor quality is discovered by the buyer, the supplier refunds the cost of defective units; if poor quality is discovered by the final consumer, the supplier shares warranty costs. Sheopuri and Zemel (2008) consider a two-level supply chain in which getting redress from the supplier for a quality failure is costly to the buyer. Chao et al. (2009) introduce contracts for sharing the product recall costs based on root cause analysis. Babich and Tang (2012) offer deferred payments to discourage product defects. They compare deferred payments, product inspection, and combined mechanisms as the tools of quality support. The combined mechanism is proved to be redundant. Singer et al. (2003) endogenize the relationship between consumer demand and quality. They model a contracting game in which the supplier is indirectly penalized for poor quality by the reduced demand experienced by the buyer from the end consumer. Baiman et al. (2000) model a one-shot interaction between a risk-neutral buyer and a risk-neutral supplier. The supplier makes an effort to produce a quality product, and the buyer makes an effort to detect defects. If penalties are enforceable, then the first-best is attained even if participants’ efforts are not contractible, but the event of bad quality detection is contractible.

Unlike these papers, we assume that the supplier can break the contract and refuse to share costs. We also assume that the buyer’s cost to get compensation from the supplier is prohibitively high. Thus, shared liability for products and warranties are not contractible. Also, unlike these authors, we consider the case of when the supplier requires advance payment, which is a common practice in China (Midler 2007).

The second stream of literature, dynamic moral hazard, has been extensively studied. A detailed review on the works in this field is given in Bolton and Dewatripont (2005). One of the closest works to ours is the seminal paper by Holmstrom and Milgrom (1987), which models long-term contracting between a principal and an agent with binary outcomes whose action set is the choice of a probability of a good outcome. An important result in Holmstrom and Milgrom (1987) is that the optimal incentive contract is stationary and has memory in the sense that the history of outcomes determines the compensation of the agent. In long-term complete contracts, the principal and the supplier commit to a compensation schedule at the beginning of the relationship. In the dynamic moral hazard literature, it is generally found that optimal contracts must have memory of past agent performance to create proper incentives. However, such contracts can be complex, especially if they are not stationary. Our model differs from Holmstrom and Milgrom (1987) in several ways. We model an infinite horizon setting with discounting in which the agent must be prepaid each period and then can be penalized for poor quality output and in which both the agent and principal are risk neutral. Most importantly, in our model the agent can deviate from the contract and break the relationship. The termination possibility and the limited liability it entails lead to optimal contracts being dynamic. Dynamic contracts with memory are complex to operationalize, and therefore in this paper, we limit ourselves to dynamic but memoryless contracts.

The third stream of related research considers stationary (Levin 2003; Taylor and Plambeck 2007a, b; Belavina and Girotra 2015) and nonstationary (Yang 2013, Plambeck and Taylor 2006) relational contracts.
Relational contracts are agreements made for repeated business interactions in which some element of the agreement is not enforceable by the court but rather by the future value of the relationship.

Levin (2003) offers a general agency setting in which repeated interactions between a principal and an agent end if promises of payments are not kept. He assumes exogenous reservation values for both players. If a contract is rejected, or if the discretionary payment is not made, then both sides receive a fixed payment representing outside opportunities. He shows that stationary contracts are optimal. We differ from Levin (2003) because in his model the only decisions the principal makes are the contract terms: the fixed payment and the contingent payment. The principal cannot commit to the contract terms. In our model, the buyer also chooses inspection effort and can commit to the contract terms. Beyond that, we have made specific modeling choices about the way the principal’s revenues are determined, that is, the inspection outcome and internal versus external costs of failures. In Levin (2003), the supplier’s type is chosen randomly every period. We model a market with homogeneous suppliers and homogeneous buyers and do not consider an adverse selection problem, that is, the cost parameters (which determine the buyer’s and supplier’s type) are deterministic. More significantly in our model, the buyer’s and supplier’s reservation values are endogenous. The breaking of the contract leads to a search of uncertain length that ends in the establishment of a new relationship with the same terms as the previous one. Thus, contract parameter choices also influence the alternative options. In Levin (2003), exogeniety allows for stationary optimal contracts; in our case, with endogenous reservation values and one-sided commitment, we get dynamic contracts. Taylor and Plambeck (2007a, b) use Levin’s approach in contracting on supplier capacity investments so they too find stationary contracts to be optimal.

Our work differs from Taylor and Plambeck (2007a, b) in several ways. We are maximizing profits for one party subject to the contract being self-enforcing for the other party. Our external option is not a repeated single period interaction between the same parties but rather a search for another party and then a new contract. They are modeling a capacity and ordering game with uncertain demand while we are modeling a quality and inspection game. Their model and analysis is leading to a stationary contracting equilibrium while we analyze a dynamic equilibrium.

Tunca and Zenios (2006) also model relational contracts and quality, but their approach is quite different from our approach and does not directly inform the issues in which we are interested. Tunca and Zenios (2006) are primarily concerned with the way two different market mechanisms interact when there is quality heterogeneity. They do not investigate the actions a buyer takes to account for uncertain quality compliance by a supplier. The manufacturer’s quality choice is binary, as opposed to continuous in our model, and we consider the distinction between internal and external failures. They also only consider one possible penalty for supplier failure, which is not to believe future quality claims, whereas in our paper we can consider a spectrum of punishment levels and possible termination.

Belavina and Girotra (2015) study how the topology of a supply chain influences the opportunity to achieve compliance with the help of stationary relational contracts. In their model, suppliers decide on wholesale prices and whether to comply with sustainability standards. A single buyer decides on quantity, and defects are discovered by final consumers. All nodes of the supply chain are known; if all nodes comply, then compliance of a final product is certain. In our work, the decision not to adulterate is not enough to provide a quality product, as unknown upstream suppliers can secretly deliver bad inputs or unintentional adulteration can occur. In Belavina and Girotra (2015), suppliers are discouraged from noncompliance and from setting higher wholesale prices by the threat of using a myopic equilibrium, when all players act in self-interest and suppliers do not comply. No other tools to enforce compliance are used. We model the dynamics of compensation, penalties, and inspection efforts to discourage noncompliance as well as certification.

Studying internal wage dynamics, Yang (2013) considers a market where homogeneous firms (buyers) and high and low type workers (suppliers) are matched. The fired supplier finds another firm and resumes work. In a symmetric perfect public equilibrium, all firms use the same strategy and all workers have the same strategy. As a result, the outside option is endogenous and the optimal contract is dynamic. But these dynamics are driven by the fact that the buyer is learning the supplier’s type so the information available to the buyer changes over time. Plambeck and Taylor (2006) model a very general supply chain relationship with both court enforceable and discretionary elements. In their setting, the business environment changes stochastically over time, and this naturally leads to a dynamic relational contract. In our case the model parameters are not changing over time, yet the optimal contracts are dynamic because the terms of the contract are used to affect the cost of the outside option.

Our paper also differs from much of the literature on quality management in that besides inspections and penalties, we also model the use of supplier certification. Hwang et al. (2006) compare inspection and certification as approaches to managing quality in a supply chain. However, they assume that penalties for quality failures are set exogenously, that it is an
3. Model

Consider a market with homogeneous buyers and homogeneous suppliers. All participants are risk neutral. Time is discrete and indexed by \( t \). To simplify the analysis, we set the coefficient of discounting to \( \alpha < 1 \) for both parties. A buyer sources a product in fixed batches from a supplier and then sells it on the market subject to quality standards such as regulations about chemical content. In period \( t = 0 \), the partners agree on the payment plan for all periods \( t \geq 0 \). At time \( t = 0 \), to initiate work with the buyer, the supplier incurs a one-time fixed cost \( F_S \), which reflects the cost of establishing the production capacity for the specific product the buyer wants. Likewise, the buyer incurs fixed start-up cost \( F_B \), which reflects the cost of contracting and training. After that, manufacturing starts; a single batch is repeatedly produced, inspected, and sold. As discussed in the introduction, we are considering a setting in which the buyer is a well-known international brand with an established reputation, but the supplier does not have large capital resources and is local to a country within which there is poor legal enforcement. The implications for our modeling approach are that (a) we formulate the contract optimization problem from the perspective of maximizing the expected profit of the buyer; (b) we assume that the buyer can commit to the terms of the contract; (c) the supplier cannot commit to contract terms and cannot be forced to pay penalties; and (d) the supplier’s profit in each period of production must be nonnegative.

In the next section, we explain how we model the main decisions made by the supplier and buyer each period, that is, the effort they, respectively, put into quality and inspection of quality. We then analyze two benchmark cases: the case when the buyer has centralized control of the supply chain and the case when the buyer does not have centralized control but contract terms are enforceable. All notation is listed in Table 1.

### 3.1. Quality and Inspection Efforts

In period \( t \geq 1 \), the supplier chooses effort \( p_t \), the probability the batch violates the quality standards of the buyer. We refer to \( p_t \) as the defect rate in period \( t \). For every batch, the supplier incurs a variable quality cost \( C_S(p_t) \). Lower \( p_t \) values reflect greater supplier effort and thus higher costs. For example, consider a buyer (a manufacturer) who outsources the production of shampoo to China and sells it to large retail chains in the United States. After the CDEA scandal of 2013, the buyer sources shampoo that is required to be free from this carcinogen. CDEA is freely sold in China and is used as a thickening, wetting, and foam stability agent in the production of detergents, shampoos, and other products. The Chinese supplier itself sources the ingredients from a variety of suppliers. In this case the defect rate reflects the effort exerted by the supplier to ensure that the inputs are CDEA-free. For simplicity we set the variable production costs of a batch that are unrelated to quality equal to zero. In this case \( C_S(p_t) \) represents the additional costs of meeting the environmental standards because CDEA-free shampoo is more expensive.

### Table 1. Definitions of Notation

<table>
<thead>
<tr>
<th>Decisions and contract terms</th>
<th>Definitions</th>
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<tbody>
<tr>
<td>( w_t )</td>
<td>Upfront payment made to the supplier each period</td>
</tr>
<tr>
<td>( FI_t )</td>
<td>Fine for defect found internally by buyer in period ( t )</td>
</tr>
<tr>
<td>( FE_t )</td>
<td>Fine for defect found externally by market in period ( t )</td>
</tr>
<tr>
<td>( q_t )</td>
<td>Buyer defect detection rate in period ( t )</td>
</tr>
<tr>
<td>( p_t )</td>
<td>Supplier defect rate in period ( t )</td>
</tr>
<tr>
<td>( C_t )</td>
<td>Vector of contract terms ((w_t, FI_t, FE_t)) in period ( t )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_S, F_B )</td>
<td>Relationship start-up costs for supplier and buyer</td>
</tr>
<tr>
<td>( \Delta S, \Delta B )</td>
<td>Supplier and Buyer per period new partner search costs</td>
</tr>
<tr>
<td>( \Pi )</td>
<td>Buyer revenue per product batch</td>
</tr>
<tr>
<td>( P_S, P_B )</td>
<td>Supplier and buyer probabilities of finding a new partner in a search period</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>Discount factor per period</td>
</tr>
<tr>
<td>( \delta )</td>
<td>Expected discounting factor for duration of supplier’s search</td>
</tr>
<tr>
<td>( \Theta )</td>
<td>Random number of periods that it takes the supplier to find a new partner</td>
</tr>
<tr>
<td>( L )</td>
<td>Supplier’s expected discounted search costs</td>
</tr>
<tr>
<td>( C_I )</td>
<td>Cost to buyer for defect found internally</td>
</tr>
<tr>
<td>( CE )</td>
<td>Cost to buyer for defect found externally by market</td>
</tr>
<tr>
<td>( C_S(q) )</td>
<td>Cost to buyer of effort to achieve detection rate ( q )</td>
</tr>
<tr>
<td>( C_S(p) )</td>
<td>Cost to supplier of effort to achieve defect rate ( p )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_B, R_C )</td>
<td>Expected continuation value in period ( t ) of the buyer and supplier</td>
</tr>
<tr>
<td>( r_B, r_C )</td>
<td>Expected profit in period ( t ) of the buyer and supplier</td>
</tr>
<tr>
<td>((w^{FB}, q^{FB}, p^{FB}, F^{FB}))</td>
<td>First-best contract terms</td>
</tr>
</tbody>
</table>
This could also include the supplier’s cost to verify that its suppliers are complying with standards.

The buyer chooses effort $q_t$, the probability of detecting a violation in a single batch. We will refer to $q_t$ as the detection rate at period $t$ and to $\bar{q}_t$ as the omission rate at period $t$. In this paper, for any probability $p$ we define $\bar{p} = 1 - p$. The detection rate $q_t$ reflects the buyer’s inspection or quality control effort with associated cost $C_B(q_t)$. Staying with the chemicals example, in our setting, the effort the buyer exerts to detect defects should not be interpreted as the number of items in a batch that he inspects. Rather, it could reflect the number of different unwanted chemicals for which the buyer tests the product. The convexity of $C_B(q_t)$ implies that there are some more likely candidates for chemicals that adulterate the product for which one would test first. If the buyer detects a defective batch, he incurs an internal remediation cost $CI$ before being able to sell the products. If a batch is defective but the buyer does not detect it, then it is released to the market, and the defects are detected with certainty by the market. In this case, the buyer incurs an external cost $CE$, which may be reputational. We assume that $CE > CI$, so it is better to detect the defect inside the firm.

We make the following assumptions about the supplier’s and buyer’s cost curves $C_S(p)$ and $C_B(q)$:

$$\lim_{p \to 0} C_S(p) = \infty, \quad C_S(1) = 0,$$

$$C_S'(p) < 0 \quad \text{and} \quad C_S''(p) > 0 \quad \text{for} \quad p \in (0; 1),$$

$$\lim_{p \to 0} C_S'(p) = -\infty, \quad C_S'(1) = 0;$$

$$C_B(0) = 0, \quad \lim_{q \to 1} C_B(q) = \infty,$$

$$C_B'(q) > 0 \quad \text{and} \quad C_B''(q) > 0 \quad \text{for} \quad q \in (0; 1),$$

$$C_B'(0) = 0, \quad \lim_{q \to 1} C_B'(q) = \infty.$$  \hfill (1)

The assumptions in (1) and (2) imply that (1) zero defect rate and absolute detection rate require infinite funds; (2) a supplier making no effort to comply with quality standards or a supplier making no effort to inspect the product both incur zero effort costs; and (3) supplier production costs are decreasing in the defect rate while buyer inspection costs are increasing in the detection rate. An example of cost functions that satisfy these conditions appears in Figure 1. We are also assuming that the buyer and supplier efforts are independent. Therefore the supplier’s quality efforts do not affect the ability of the buyer to detect a defect when one occurs.

### 3.2. Illustrative Numerical Example

To illustrate the features of the model and some of our results, we construct a numerical example. Consider a buyer who outsources the production of a product to China and sells it to large retail chains in the United States. We assume that the buyer can sell the product to retailers for $4.0 per unit and that the supplier’s production costs are at least $3.0 per unit. Thus, if every month 180,000 units are produced, then $180 K is the buyer’s income and establishes an upper bound on what can be spent on quality per batch. Let the discount rate be 20% per year corresponding to parameter $\alpha = 0.9816$. For the purposes of these numerical experiments, we use the following functional forms for the quality and inspection costs of the supplier and buyer that satisfy assumptions (1) and (2):

$$C_S(p) = b_S(p^{-a_S} - a_Sp - 1), \quad a_S > 0, \quad b_S > 0;$$

$$C_B(q) = b_B(q^{-a_B} - a_Bq - 1), \quad a_B > 0, \quad b_B > 0.$$  \hfill (3)

Given that the compliance failures described in the introduction are not very frequent, we think it is realistic to have quality and inspection cost functions such that at a low cost, most of the time, defects do not reach the market, but perfect prevention is unattainable. To that end we set the parameters $a_S \approx 0.07, b_S = 300,000, a_B \approx 0.9$ and $b_B = 3,000$ so that the supplier’s and buyer’s cost curves represent the case shown in Figure 1.

Here, to provide a 99% guarantee that a bad batch is caught, the buyer spends 100% of his potential revenue.

**Figure 1.** (Color online) Supplier and Buyer Quality Cost Curves
To ensure a 60% detection rate, the buyer needs to spend 1% of potential revenue. For the supplier, it costs 51% of the potential buyer sales revenue ($180 K) to make the efforts to ensure a 1% defect rate. We do not claim that these cost curves are representative of a specific real case; they are purely for illustration. We have experimented with a wide range of quality and detection curve parameter values and observed similar results for buyer and supplier behavior and outcomes.

### 3.3. Centralized Production and Outsourcing Under Enforceable Contracts

In this subsection, we consider several benchmark models to develop our intuition about the problem setting. First, we characterize the first-best solution for a centralized supply chain (Problem 1). Second, we construct benchmark models with enforceable defect rates or fines for outsourcing the production to an external supplier (Problems 2 and 3).

Suppose both the supplier and the buyer are centrally controlled divisions of the same firm. In the initial period $t = 0$, both participants incur fixed production start-up costs $F_S$ and $F_B$. Manufacturing starts in period $t = 1$. In every period $t \geq 1$, a single batch is repeatedly produced, inspected, and sold. The buyer makes transfer payments to the supplier for the cost of every batch and sells the product, and the firm receives revenue $\Pi$. In this setup, the first-best outcome is achieved in every stage. Therefore, the stationary policy $(p_t, q_t) = (p, q)$ for $t \geq 1$, is optimal. The firm maximizes expected discounted profits by solving for the optimal stationary quality level $p$ and inspection level $q$ in Problem 1.

#### Problem 1 (Centralized (First Best)).

$$
\max_{p,q} \frac{\alpha}{1-\alpha} (\Pi - C_S(p) - C_B(q) - p(qCI + qCE)) - (F_S + F_B).
$$

From the assumptions (1) and (2), the unconstrained Problem 1 has an internal optimal solution that satisfies first-order conditions (3) and (4). We assume that the total production and noncompliance costs per batch, $C_S(p) + C_B(q)$, are strictly pseudo-convex. This assumption guarantees the unique global maximum for the expected profit of the centralized supply chain. We denote this solution by $(p^*, q^*)$ and assume that it generates nonnegative profit to avoid trivial cases. For the same reason, we also assume that the buyer incurs negative profits if $p = 1$. The firm’s problem can be viewed as finding the most cost effective way to prevent defects from reaching the end consumer. An interior solution implies that the firm wants some quality control conducted both on the production side and on the inspection side:

$$
-C_S^*(p) = qCI + qCE, \quad (3)
$$
$$
-C_B^*(q) = p(CI - CE). \quad (4)
$$

Now suppose that the buyer and supplier are separate firms. The two parties must then establish a contract. If the supplier’s quality choice $p_t$ is enforceable, then we can consider a contract in which the buyer specifies $(w_t, q_t, p_t)$, where $w_t$ is an upfront payment made to the supplier each period. Consider the stationary equilibrium $(w_t, q_t, p_t) = (w_t, q_t, p_t)$, $t \geq 1$. The buyer solves Problem 2 assuming w.l.o.g. (without loss of generality) that the supplier’s reservation profit is 0.

#### Problem 2 (Enforceable Defect Rate $p_t$).

$$
\max_{w,q} \frac{\alpha}{1-\alpha} (\Pi - w - C_B(q) - p(qCI + qCE)) - F_B
$$

s.t. $w - \frac{1-\alpha}{\alpha} F_S - C_S(p) \geq 0 \quad w \geq 0, \quad q \in [0;1]. \quad (6)
$$

Equation (6) is the supplier’s per-period profit. Problem 2 is reduced to Problem 1 by setting $w = ((1-\alpha)/\alpha) \cdot F_S + C_S(p)$, so, the first-best outcome can be achieved, and the solution $(w_t, q_t, p_t) = (w_t, q_t, p_t)$ forms a stationary equilibrium. The buyer’s payment to the supplier compensates him for production costs and amortizes the start-up costs over the lifetime of the relationship, which is infinite here. Problems 1 and 2 are equivalent to multiperiod formulations of the model in Baiman et al. (2000) in the cases when the first-best outcome is achievable with some small modeling differences. The ability to achieve first-best in Problems 1 and 2 corresponds to Propositions 1 and 2A in Baiman et al. (2000).

If the defect rate $p_t$ is not enforceable, then the buyer can use fines to create an incentive for the supplier to exert quality effort. Let the buyer’s inspection effort $q_t$ be public and verifiable, and let the contract penalize the supplier $FI_t$ for internal failures and $FE_t$ for external failures. We consider three scenarios under a stationary equilibrium $(w_t, q_t, p_t, FI_t, FE_t)$, $t \geq 1$. Scenario A: both $FI_t$ and $FE_t$ are enforceable, and the supplier pays fine $FI_t$ in case of an internal failure and $FE_t$ in case of an external failure. Scenario B: only $FI_t$ is enforceable. Scenario C: only $FE_t$ is enforceable. The buyer’s problem is described by Problem 3.

#### Problem 3 (Unenforceable Defect Rate $p_t$).

$$
\max_{w,q,FI,FE} \frac{\alpha}{1-\alpha} \left( \Pi - \frac{1}{\alpha} F_B - w - C_B(q) - p(qCI + qCE) \right)
$$

$$
\quad \quad \quad - p(qCI - FI) + \hat{q}(FE - CE))
$$

s.t. $p = \arg\max_{\tilde{p} \in [0;1]} \frac{\alpha}{1-\alpha} \left( w - \frac{1}{\alpha} F_S - C_S(\tilde{p}) - \tilde{p}(FI + qFE) \right)
$$

$$
\quad \quad \quad - \hat{p}(FI + qFE), \quad (7)
$$

$$
\frac{1}{\alpha} (w - \frac{1}{\alpha} F_S - C_S(p) - p(qFI + qFE)) \geq 0, \quad w, FI, \quad \text{and} \quad FE \geq 0, \quad q \in [0;1]. \quad (8)
$$
Scenario A has no additional constraints. Constraint (7) is relevant to Scenario B only. Constraint (8) belongs to Scenario C only.

\[ FE = 0, \]
\[ I = 0. \]

The first-best is achievable in all three cases. To see this, note that if the supplier maximizes his goal function then, from (7), \(-C_1(p) = qFI + \tilde{q}FE\). It is necessary to set the fines so that \(qCI + \tilde{q} CE = q FI + \tilde{q} FE\), which forces the supplier to internalize the cost to the buyer of a defective batch. In Scenario A, where both penalties are enforceable, one of the possible ways to achieve the first-best outcome is to set \(FI = CI\) and \(FE = CE\). In Scenario B, where \(FE\) is not enforceable, from (4), the first-best is achieved by setting \(FI = CI + (\tilde{q}/q) CE\). In Scenario C, where \(FI\) is not enforceable, the first best is enough to set \(FE = (q/\tilde{q}) CI + CE\). Because the buyer will set \(w = ((1-\alpha)/\alpha)F_S + C_S(p) + p(qFI + \tilde{q} FE)\) making (6) binding, the buyer’s FOC is simplified to (4).

Let \((w, q, p, FI, FE)\) be the solution to Problem 3. As the first-best effort is achievable in every period, then the stationary equilibrium \((w_t, q_t, p_t, \bar{F}_{It}, \bar{F}_{E_t})\) is optimal. We note that when both \(FI\) and \(FE\) are enforceable, it is possible to make the supplier choose any target defect rate \(0 < \tilde{p} \leq 1\) with equal fines by setting

\[ F = FI = FE = -C_1(\tilde{p}). \]

Equation (9) means that the fine is set equal to the marginal cost of better quality. The first-best is achieved by setting \(F = FB = qFB CI + \tilde{q}FB CE\). Then the optimal stationary equilibrium can be simplified to \((w, q, p, F)\). In this case, the inspection level \(q\) does not affect the defect rate \(p\), and it is not necessary to have \(q\) verifiable. These two characteristics of the contract, that a single fine can be used for both types of failures and that the supplier’s effort is independent of the buyer’s effort, will carry over to our model of contracts with unenforceable fines. The analysis of Problem 3 corresponds to Proposition 3 in Baiman et al. (2000), where our enforceable fine is equivalent to their “contractible event” (p. 780). In the rest of the paper we focus on cases where none of the fines are enforceable. In Baiman et al. (2000) this case is studied (for a single period), but with the buyer given the ability to return the product for some compensation in a single period and with no consideration of the alternative when the supplier does not comply (i.e., a fine for an internal failure is enforceable, but the buyer does not need to show that there was a failure). In this paper we are not interested in the case of a buyer “pretending” that there was a quality failure.

3.4. Analysis of Nonenforceable Dynamic Contracts

When fines are unenforceable, they become discretionary payments by the supplier to the buyer to compensate for defects. Thus a relational contract framework is appropriate. Expanding upon the benchmark models, we consider the following model of the interaction between buyer and supplier, which forms a dynamic repeated game. In period 0 both sides incur respective start-up costs, and the buyer commits to a contract \(C_i(q_t, \bar{F}_{It}, \bar{F}_{E_t})\) for all periods \(t \in [1; \infty)\) with \(w_t, \bar{F}_{It}, \bar{F}_{E_t} \in \mathbb{R}^+\). In each production period \(t \geq 1\) we have the following sequence of events:

1. The supplier receives payment \(w_t\).
2. The supplier chooses a quality effort \(p_t\) and produces a batch, and the buyer simultaneously chooses inspection effort \(q_t\).
3. The quality of the batch is revealed. Either it is good, \((y_t = 0)\), defective and detected internally by the buyer \((y_t = 1)\), or defective and detected externally by the consumer \((y_t = 2)\).
4. The buyer imposes a fine on the supplier, \(F_t\), if \(y_t = 1\) and \(FE_t\), if \(y_t = 2\).
5. If the supplier pays any fines imposed by the buyer then the sequence repeats. If the supplier refuses to pay a fine, the relationship is terminated, and both parties begin searching for new partners.

As is common in the literature on repeated games, we assume the buyer employs a trigger strategy. If the fines are not paid, the buyer permanently fires the supplier and terminates the contract. Termination is the harshest penalty available to the buyer. If the supplier is already refusing to pay a fine, then imposing an additional fine will not achieve anything.

In case of termination, both the supplier and the buyer must conduct a costly search for new trading partners. The search starts in the next period \(t + 1\). The probabilities of finding new partners for the supplier and for the buyer in any period are, respectively, \(P_s\) and \(P_b\). While the buyer and the supplier search, they do not generate any profits and incur search costs \(C_s\) and \(C_b\) every period. Once a new partner is found at time \(\tau\), the game starts again, and the partners incur new fixed costs in period \(\tau + 1\). If a contract is terminated, let \(\Theta\) be the random number of periods that it takes the supplier to find a new partner (i.e., a geometric random variable with mean \(1/P_s\)); then we define a discounting factor for the delay in starting a new relationship as \(\delta = E[\alpha^\Theta]\). We define \(L = C_sE[\sum_{t=0}^{\Theta} \alpha^{t-1}]\) as the supplier’s expected discounted search costs.

Our solution approach is to search for a symmetric perfect public equilibrium (i.e., all buyers use the same strategy, and all suppliers use the same strategy) in which neither buyer nor supplier knows about the partner’s previous relationships. We focus on those equilibria that maximize the buyer’s expected profit.
Let \( h^t = (w_1, F_1, F_2, q_1, y_{11}, \ldots, w_{t-1}, F_{t-1}, q_{t-1}, y_{t-1}) \) be the public history for a current relationship up to time \( t \in [1; \infty] \). We include the buyer’s efforts \( q_t \) in the public history because the kind of detection efforts in which he engages are publicized and can be observed by suppliers (e.g., inspections of facilities or requirements to send samples to third-party labs). The knowledge of whether or not the supplier pays a fine is not included in the history because once he fails to pay the fine, the relationship is terminated and a new history begins. Let \( H^t \) be the set of possible public histories up to time \( t \). We define a relational contract as a complete plan for a relationship. For each period \( t \) and all public histories \( h^t \in H^t \), a relational contract describes the following actions as functions of public history: (1) the contract the buyer offers \( C_t = (w_t, F_t, F_t) \) and (2) the effort level the buyer and supplier choose \((p_t, q_t)\).

Let \( R_{B_t} \) and \( R_{S_t} \) be the respective continuation values of the game in period \( t \geq 0 \) on the equilibrium path when both the buyer and the supplier are complying with the contract terms. Let \( r_{B_t} \) and \( r_{S_t} \) be the corresponding expected stage profits. In any one period \( t \geq 1 \) the supplier has three ways to potentially deviate from the contract. He can refuse to pay any fines, refuse to pay external fines, and refuse to pay internal fines. We denote the continuation values if the supplier makes a single period deviation of any of these three types as \( R^X_t \) \((X \in \{A, E, I\} \)”any,” “external,” “internal”). We denote the corresponding defect rate chosen by the supplier as \( p^X_t \). \( X \in \{A, E, I\} \). The following equations establish the relationships between the actions taken by the buyer and the supplier and their payoffs for all \( t \geq 0 \).

For \( t = 0 \), \( R_{B_0} = -F_B + \alpha R_{B_1} \) and \( R_{S_0} = -F_S + \alpha R_{S_1} \).

For all \( t \geq 1 \)
\[
R_{B_t} = \max_{q_t \in [0,1]} \{ \Pi - w_t - C_t(q_t) - p_t(q_t)(CI - F_t) + \bar{q}_t(CE - FE_t) + \alpha R_{B(t+1)} \},
\]
\[
R_{S_t} = \max_{p_t \in [0,1]} \{ w_t - C_t(p_t) - p_t(q_t)(F_t + \bar{q}_t + FE_t) + \alpha R_{S(t+1)} \},
\]
\[
R^A_{S_t} = \max_{p_t^A \in [0,1]} \{ w_t - C_t(p_t^A) + \alpha(p_t^A(\delta R_{S_0} - L)) + p_t^A \bar{q}_t R_{S(t+1)} \},
\]
\[
R^E_{S_t} = \max_{p_t^E \in [0,1]} \{ w_t - C_t(p_t^E) - p_t^E q_t F_t + \alpha(p_t^E q_t(\delta R_{S_0} - L)) + (p_t^E + p_t^E \bar{q}_t) R_{S(t+1)} \},
\]
\[
R^I_{S_t} = \max_{p_t^I \in [0,1]} \{ w_t - C_t(p_t^I) - p_t^I q_t F_t + \alpha(p_t^I q_t(\delta R_{S_0} - L)) + (p_t^I + p_t^I \bar{q}_t) R_{S(t+1)} \}.
\]

Equation (12) defines the total value of the relationship for each party and captures the start-up costs. There are no actions taken in period 0. Equation (10) shows how given contract terms \( C_t \), the buyer’s action, \( q_t \), affects the payoff in period \( t \) in a relational equilibrium. Equation (11) shows the same for the supplier. Equations (15a)–(15c) define the expected continuation profit for the supplier if he intends to deviate in period \( t \). In Equation (12) the supplier does not pay “Any” fine if there is a defect, hence the superscript “A.” The first two terms give the current period profit, while the third term shows the expected profit from future periods. If there is no defect then there is no need to deviate, and the supplier receives the continuation profit from the current contract, \( R_{S(t+1)} \) (which is defined by Equation (11)). If there is a defect, then the current contract will be terminated because the defect will be discovered internally or externally, a fine will be levied on the supplier by the buyer, and the supplier will refuse to pay. When the contract is terminated, the supplier receives the future expected profit of a new contract, \( R_{S_0} \) (defined in (12)), discounted by \( \delta \), the expected discounting factor for the time to find a new partner. The supplier also incurs the expected search cost \( L \). Equations (15b) and (15c) show what happens if the supplier deviates by not paying the internal or external fine, respectively, (superscripts “I” and “E”).

In the case when the internal fine is ignored (13), the contract is terminated when there is a defect that is detected internally by the buyer (with probability \( p_t^I \)). In the case when the external fine is ignored (14), the contract is terminated when there is a defect that is not detected by the buyer (with probability \( p_t^E \)).

A solution of the following program (DRE) is a dynamic relational equilibrium optimal for the buyer:

\[
\begin{align*}
\text{DRE: } & \max_{c_t, q_t, \delta \in [0, 1; \infty]} R_{B_0} \\
\text{s.t. } & R_{S_t} \geq \max_{X \in \{A, E, I\}} R^X_{S_t} \quad \text{for all } t \in [1; \infty], \quad (16) \\
& R_{B_0} \geq 0 \quad \text{and} \quad R_{S_0} \geq 0, \quad (17a) \\
& R_{S_t} - \alpha R_{S(t+1)} \geq 0 \quad \text{for all } t \in [1; \infty]. \quad (17b)
\end{align*}
\]

In the DRE the buyer is committing to a payment to the supplier, fine (internal and external), and inspection effort for each period to maximize his own expected profit from the relationship, \( R_{B_B} \). Equation (15) is an incentive compatibility constraint for the supplier to prefer to adhere to the contract terms and not to deviate in any period. Equation (16) gives participation constraints for the supplier and the buyer. Equation (17a) is the requirement that the supplier is not producing at a loss in any production period.

We note that because the DRE is formulated as maximizing the buyer’s expected profit and because we have assumed that the buyer can commit to the terms of the contract, we do not need incentive compatibility constraints for the buyer. This means that the buyer is better off because the problem is less constrained.
(i.e., the reputation of the buyer gives credibility to his contract commitment and thus gives the buyer a larger profit than if he were not able to commit). Also, as a result, the buyer-related search parameters $\tilde{C}_p$ and $P_{R^0}$ are irrelevant to the formulation. Similarly, the parameter $F_S$ is not important as long as the buyer participation constraint $R_{S0} \geq 0$ can be satisfied.

**Lemma 3.1.** The DRE can be simplified as follows:

\[
\text{DRE} : \max_{w_t, F_t, q_t} R_{S0} \\
\text{s.t.} \quad R_{S0} \geq 0, \quad R_{S1} \geq 0, \quad r_{S1} \geq 0; \quad C_t(p_t) = F_t; \quad \alpha(R_{S(t+1)} - (\delta R_{S0} - L)) \geq F_t, \quad t \geq 1; \quad w_t \geq 0, \quad q_t \in [0;1], \quad F_t \geq 0.
\]

**Proof.** See the online appendix.

In this reformulation we have that, w.l.o.g., the internal and external fines can be set equal to each other so that there is only one fine to determine for each period. As a result, $q_t$ drops out of Equation (11). Equation (18) indicates that the supplier’s defect rate is completely determined by the fine. Equation (19) is a new incentive compatibility constraint for the supplier (replacing Equation (16)), which can be interpreted as follows: the supplier does not deviate if the expected discounted loss from contract termination is greater than the fine. The fact that $R_{S0}$ is in the incentive compatibility constraint indicates that the value of the supplier’s outside option is endogenous to the contracting problem. Proposition 3.1 gives conditions for the DRE to achieve the first-best outcome.

**Proposition 3.1.** (a) The necessary and sufficient condition for a stationary solution to DRE to achieve the first-best is $F_S = (1 - \alpha)S_F$, and $\alpha L \geq F_F^\alpha$. (b) The necessary and sufficient condition for a dynamic solution to DRE to achieve the first-best is $\alpha^{-1} F_S + \alpha L \geq F_F^\alpha$.

Proposition 3.1 shows that if the supplier’s initial investment into a relationship and expected discounted search costs for a new partner are high (i.e., if the switching/termination costs for a supplier are high), then the feasible parameter space for the first-best solution is larger. It also shows that a dynamic equilibrium achieves the first-best outcome for a wider range of parameters. The difference is in the additional discounting factor on the supplier start-up cost. Since the supplier is not paid the same in each period in the DRE, it is possible to delay compensating him for the start-up costs; that is reflected in the $\alpha^{-1}$ factor in condition (b) of the proposition. If the supplier must be immediately compensated for his start-up costs, it is equivalent to setting $F_S = 0$. From Proposition 3.1 we can see that this would reduce one advantage that a dynamic solution to the DRE has over a stationary solution.

**Proposition 3.2.** Assuming DRE is feasible, (a) if $F_S = 0$, and the first-best solution is achieved, then this equilibrium is unique. (b) Otherwise, if $F_S > F_F^\alpha$ for some $t \geq 1$, then DRE has infinitely many optima.

Proposition 3.2 shows that when $F_S = 0$, if the first-best is achievable, there is no difference between a stationary and a dynamic solution to the DRE. We will see in the following that when the first best is unachievable, then even with $F_S = 0$, a nonstationary contract is optimal. The nonstationary contract gives the buyer a mechanism to inflate the termination costs of the supplier, thus gaining additional leverage and improving supplier compliance with quality standards. Proposition 3.3 shows that when the first best cannot be achieved, there is an optimal equilibrium characterized by a particular period $T$ at which point the fine, $F_t$, is set to the same fine as in the first-best case and is constant after that point. In periods before $T$ the fine will be increasing. The fine determines the defect rate selected by the supplier and the inspection level selected by the buyer, so the dynamics of penalty $F_t$ drive the dynamics of these decisions as well. (Note: there can be cases in which $T = 1$ and $\infty$.) These dynamics lead to a situation in which, in the initial periods of a contract, the supplier makes less money than in later periods.

**Proposition 3.3.** If a solution to the DRE exists then we have the following:

1. If the first-best is achieved, then one of the possible optimal equilibria has $F_t$, $p_t$, and $q_t$ at their first-best levels for all $t$; the per-period payment $w_t$ is set so that in the first period the supplier has zero profit ($r_{S1} = 0$); and in subsequent periods, the supplier’s profit is at a level that only recoups the start-up cost ($r_{S1} = ((1 - \alpha)/\alpha^2)F_S$, $t \geq 2$).
2. If the first-best cannot be achieved, then there exists an optimal equilibrium defined by a critical time period $T$ that determines when the fine is set at the first-best level for the first time and stays at that level for all $t \geq T$.
   a. If $T = 1$, then the fine is set at the first-best level in each period, the inspection and quality efforts are at the first-best levels. The supplier has a positive surplus.
   b. If $1 < T < \infty$ then the fine increases each period until $T$, at which point it stays constant at the first-best level. As a result, the inspection effort and the defect rate are both decreasing until $T$ and then stay at the first-best levels. The supplier has no profit until time $T$ and a positive profit from time $T$ onward.
   c. If $T = \infty$, then in all periods the fine is set at a constant less than the first-best value and the supplier makes no profit. This can only occur if $F_S = 0$.

The structure of the equilibrium in Proposition 3.3 when first-best is not achieved is such that all the contract parameters can be derived from the fine in the first production period, $F_1$. Corollary 3.1 provides the specific relationships.
Corollary 3.1. Suppose there exists a relational equilibrium. If the first-best outcome cannot be achieved, then the optimal equilibrium described in Proposition 3.3 has the following properties.

(a) The supplier’s total expected discounted profit is \( R_{S0} = \alpha(F_1 - \alpha^{-1}F_S - aL)/(1 - \delta\alpha^2) \).

(b) The fine in period \( t = 1 \), \( F_1 \) will fall in the range: \( [\alpha^{-1}F_S + aL; F_{FB}] \).

(c) The fine in all other periods \( 1 < t < T \) will be determined recursively by the following equation: \( F_t = F_{t-1}/\alpha + ((1 - \alpha)(\delta F_S - L))/((1 - \delta\alpha^2)) \).

(d) For \( 1 \leq t \leq T, F_{t+1} > F_t, p_t > p_{t+1}, q_t > q_{t+1} \).

(e) The supplier’s profit in each period \( t \geq 1 \) is

\[
\begin{align*}
\text{if } &1 \leq t < T, \\
r_{S1} & = \begin{cases} 
0 & \text{if } t = 1 \\
F_{t-1} - F_{FB} & \text{if } t = T, \\
(1 - \alpha)(\delta F_1 - \delta F_S - L)/\alpha & \text{if } t > T.
\end{cases}
\end{align*}
\]

(f) The supplier’s profit after period \( T \) is always greater than his profit in period \( T \).

(g) The per-period payment from buyer to supplier, \( w_t \), is increasing for \( 1 \leq t \leq T \) and is constant for \( t \geq T + 1 \).

(h) The buyer’s profit in each period, \( r_{B1} \), is increasing until period \( T - 1 \). After period \( T \) the buyer’s profit remains constant at a level below that in period \( T \). \( r_{B1} \) itself may be larger or smaller than \( r_{B1(T-1)} \).

The challenge for the buyer is that if the quality target is initially high then the cost of production will be high for the supplier. Therefore the upfront payment the buyer must make to the supplier will be large and at risk of loss if the supplier deviates from the contract. Deviation may be attractive to the supplier if the termination costs are not too high. This is why it is optimal for the buyer to gradually increase the fine and his payment to the supplier over time. The buyer also creates an incentive for the supplier to stay in the contract by deferring payment of the start-up cost \( F_S \) until after period \( T \) and giving the supplier a profit in these later periods. Once the partners get past period \( T \), the quality level is at the first-best level and the fines for defects are high. High fines create an incentive for the supplier to deviate by refusing to pay. However, the deferral of positive profits and compensation for \( F_S \) until period \( T \) is the incentive for the supplier to pay higher fines when they are assessed. In every further period, as the future rewards are closer and discounted less, the supplier becomes less willing to deviate and the buyer is able to charge higher fines.

The special cases of \( T = 1 \) and \( T = \infty \) are caused by particular parameter combinations. If the termination costs are large enough, then it is possible that from the first period the buyer can set the fines at the first-best level. If \( F_S = 0 \) and the search costs are relatively low, the supplier has more power; and if \( aL \) is close enough to \( F_{FB} \), then we get the third equilibrium in which the fine is constant but below \( F_{FB} \) and the supplier makes no profit. This could be optimal if the additional profit the buyer would have to provide the supplier to boost quality does not gain him much in terms of fewer defect costs. Corollary 3.1 also shows that finding the profit for the optimal DRE just involves one-dimensional search for \( F_1 \) on the feasible interval \( [\alpha^{-1}F_S + aL; F_{FB}] \) and calculating \( R_{B0} \).

Continuing the base case numerical example from Section 3.2, we set \( CI = $180K \) to replace the batch and set \( CE = 2CI = $360K \). We assume that it takes the supplier three months on average to find a new buyer, meaning that the supplier’s probability of finding a new partner in any given month \( 1 - p_S \) is 33%, and we set the supplier’s cost per search period \( C_S \) to $3,000. We set \( F_S = \Pi = $180K \), that is, equivalent to one month of sales profit. As the buyer’s decisions are enforceable, and we are restricting ourselves to relational contracts, the buyer’s corresponding parameters—\( C_B, P_B, \) and \( F_B \)—are not relevant. The parameters for this example are summarized in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base case value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_S, F_B )</td>
<td>$180,000, $0</td>
</tr>
<tr>
<td>( C_S )</td>
<td>$3,000</td>
</tr>
<tr>
<td>( \Pi )</td>
<td>$180,000</td>
</tr>
<tr>
<td>( P_S )</td>
<td>0.6667</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>0.9816</td>
</tr>
<tr>
<td>( \Theta )</td>
<td>Three months</td>
</tr>
<tr>
<td>( L )</td>
<td>$8,680</td>
</tr>
<tr>
<td>( CI )</td>
<td>$180,000</td>
</tr>
<tr>
<td>( CE )</td>
<td>$360,000</td>
</tr>
</tbody>
</table>

Table 2. Parameter Values for Numerical Example—Base Case

The optimal dynamic equilibrium for the base case, we use the procedure described in Corollary 3.1. To determine \( w_t, F_t, q_t \), and \( p_t \) for \( t \geq 1 \), we vary the fine for the first production period \( F_1 \) in the interval \( [\alpha^{-1}F_S + aL; F_{FB}] \); that is, we tabulate the interval \([191,900; 243,700]\). The optimal relational dynamic equilibrium for the base case has the following characteristics: \( F_1 = $191,900, T = 15, R_{S0} = $11, \) and \( R_{B0} \approx $6,206,000; \) that is, the DRE does not quite achieve first best. The dynamics of the relationship in the base case are displayed in Figure 2 and can be seen to have the properties described in Proposition 3.3 (part 2) and Corollary 3.1.

4. Sensitivity Analysis

Here we use sensitivity analysis to identify the factors that influence the efficiency of the DRE relative to first best. We vary the external failure cost from \( CI \) to \( 50 \times CI \), the supplier’s initial investment \( F_S \) from 0%
Figure 2. (Color online) Optimal Dynamic Equilibrium in the Base Case

Note. See Table 2 for parameters.

to 100% of a month’s revenue, and the expected search length between one and six months. In Table 3, we show the efficiency of the DRE for the buyer and for the entire supply chain. We see that higher external failure costs $CE$ and shorter new partner search times for the supplier both undermine contract efficiency. Higher $CE$ values put pressure on the buyer to prevent defects from getting to the market, but because of agency issues during the earlier stages of the contract, the buyer must exert more effort on this than he would in the first-best case. The expected time it takes for the supplier to find a new partner reflects the relative power of the two parties in the relationship. If the expected time is long, then the buyer has more leverage over the supplier and can structure the contract in a more efficient manner.

Looking across the columns of Table 3, the negative effects of a large external failure cost or short new partner search time are counteracted by relatively small supplier initial investment costs $F_S$. We can also see that a large part of the efficiency loss to the buyer is a shift in profit to the supplier, not a loss to the supply chain as a whole. For example, looking at Table 3, if $CE = CI$, the expected new partner search time is three months,
and the start-up cost $F_S$ is 0, then the efficiency of the contract for the buyer is 94%. If the external cost is much higher (e.g., $CE = 25CI$), then the efficiency of the contract drops to 77%, a drop of approximately 17%. However, in this scenario the drop in the total supply chain profit is from 98% to 91%, or about 7%. This means that almost one-half of the change in the efficiency of the contract for the buyer is a shift of profits to the supplier.

In Table 4 we report the first period values of $q_t$, $w_t$, and $p_t$ for the DRE in monthly operations. From our results in Section 3 we know that $q_t$ is decreasing in $t$, $w_t$ is increasing in $t$, and $p_t$ is decreasing in $t$, so looking at the first period values gives us an indication of how the contract terms reflect the business conditions. We can see that when $CE = CI$, the buyer can afford to put all of the burden on the supplier to prevent defects from reaching the consumer, but if $CE$ is large the buyer must exert a large inspection effort. As the supplier’s new partner search time increases, the buyer can force him to increase quality (reduce the defect rate) and the buyer can spend less on inspections. This requires the buyer to increase the payment to the supplier, and $w_t$ increases as well. When $F_S$ increases, the buyer’s leverage over the supplier also increases, and we see that the defect rate decreases; but the payment to the supplier increases both because of the increased supplier quality cost and the increase in $F_S$.

Even though we saw that increasing $F_S$ increases contract efficiency, it does not mean that the buyer always prefers high $F_S$. Table 5 shows buyer profit when $CE = CI$. As $F_S$ grows, the buyer can charge higher fines because of the hold-up problem, but the buyer needs to compensate the supplier’s initial investment. As a result, the buyer profit is maximal when $F_S$ is equal to the revenue from 15 days of operations. The lower values of $F_S$ do not discipline the supplier enough; the higher values are too costly for the buyer. At the same time, as Table 3 shows, the relative efficiency of the DRE grows in $F_S$. When $F_S$ is sufficiently high that the conditions in Proposition 3.1 hold, the DRE achieves the first-best outcome.

In summary, our memoryless contract performs better the higher the discounting coefficient is and the lower the expected failure cost is compared to revenue. The efficiency increases in the supplier’s expected time of search for another buyer and in the supplier’s initial investment. One of the drivers of the magnitude of the discounting coefficient is the frequency of transactions between the trading partners. Higher frequency improves efficiency. The DRE contract performed very well relative to first best for a wide range of parameter values, and it is not clear whether contracts with memory can significantly outperform.

### Table 4. $q_t$, $w_t$, and $p_t$ for Different Values of External Failure Cost, Supplier Expected Search Time, and Supplier Start-up Cost

<table>
<thead>
<tr>
<th>CE</th>
<th>Expected search length (months)</th>
<th>$q_t$ (DRE) (%)</th>
<th>$w_t$ (DRE) ($)</th>
<th>$p_t$ (DRE) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CI$</td>
<td>$≤ 1$</td>
<td>$F_s$ (% of monthly rev)</td>
<td>$F_s$ (% of monthly rev)</td>
<td>$F_s$ (% of monthly rev)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0$</td>
<td>$50%$</td>
<td>$100%$</td>
</tr>
<tr>
<td></td>
<td>$3$</td>
<td>14,638</td>
<td>37,552</td>
<td>50,566</td>
</tr>
<tr>
<td></td>
<td>$6$</td>
<td>20,141</td>
<td>38,643</td>
<td>50,566</td>
</tr>
<tr>
<td>$2CI$</td>
<td>$≤ 1$</td>
<td>25,021</td>
<td>40,067</td>
<td>50,566</td>
</tr>
<tr>
<td></td>
<td>$3$</td>
<td>15,437</td>
<td>37,552</td>
<td>51,308</td>
</tr>
<tr>
<td></td>
<td>$6$</td>
<td>21,818</td>
<td>38,643</td>
<td>51,946</td>
</tr>
<tr>
<td>$25CI$</td>
<td>$≤ 1$</td>
<td>27,736</td>
<td>40,067</td>
<td>52,796</td>
</tr>
<tr>
<td></td>
<td>$3$</td>
<td>21,735</td>
<td>39,770</td>
<td>51,308</td>
</tr>
<tr>
<td></td>
<td>$6$</td>
<td>29,903</td>
<td>41,740</td>
<td>51,946</td>
</tr>
<tr>
<td>$50CI$</td>
<td>$≤ 2$</td>
<td>34,887</td>
<td>44,725</td>
<td>52,796</td>
</tr>
<tr>
<td></td>
<td>$9$</td>
<td>32,041</td>
<td>43,493</td>
<td>52,270</td>
</tr>
<tr>
<td></td>
<td>$12$</td>
<td>40,030</td>
<td>47,277</td>
<td>54,534</td>
</tr>
</tbody>
</table>

Note. Base case in bold.

### Table 5. Buyer Profit with $CE = CI$

<table>
<thead>
<tr>
<th>Expected search length (months)</th>
<th>Buyer profit ($)</th>
<th>$F_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0$</td>
<td>50% monthly revenue</td>
</tr>
<tr>
<td>$≤ 1$</td>
<td>6,363,075</td>
<td>6,764,360</td>
</tr>
<tr>
<td>$3$</td>
<td>6,466,078</td>
<td>6,772,836</td>
</tr>
<tr>
<td>$6$</td>
<td>6,556,767</td>
<td>6,782,228</td>
</tr>
</tbody>
</table>

5. Dynamic Relational Contracts with Certification

As we discussed in the introduction, one tool for managing compliance is for suppliers to get certification of their production process compliance to industry norms.
through a third party that may or may not be acting as an agent for the buyer. This third party would do upfront work with the supplier before production starts to establish the certification and possibly do periodic monitoring as part of maintaining the certification. Certification helps establish some transparency about the supplier’s quality assurance efforts. The upfront work to establish the certification is intended to make monitoring adherence to the norms easy for the third party. In our framework, we can represent such certification as setting an upper bound $\tilde{p}$ on the supplier’s defect rate $p_t$ in any period $t$. Certification has a cost, and our approach is to model it as a one-time start-up cost that we assume w.l.o.g. is completely borne by the buyer as part of his start-up costs $F_B$. In the following, we focus on studying how certification structurally changes the outcomes of the relationship between buyer and supplier, and thus we set the certification costs to zero. Once we know the potential benefits of certification we can always compare that to its cost.

Here we consider a modification of the dynamic relational contract from Section 3 incorporating certification, denoted CDRE, in which the supplier’s choice of defect rate in any period is constrained from above by $\tilde{p}$.

**Lemma 5.1.** CDRE can be formulated as follows:

$$\max_{w_t, F_t, \tilde{p}} R_{g0}$$

$$\text{s.t. } R_{g0} \geq 0, \quad R_{s0} \geq 0, \quad r_{st} \geq 0, \quad p_t = \arg\max_{p_{t(\tilde{p})}} \{w_t - C_S(p) - pF_t\}, \quad (21)$$

$$\alpha(R_{st+1} - (\delta R_{s0} - L)) \geq I_{p_{t(\tilde{p})}p}F_t + I_{p_{t(\tilde{p})}p}C_S(\tilde{p}), \quad t \geq 1. \quad (22)$$

The main difference between CDRE and DRE can be seen in Equation (22) and in the formulation of the nondeviation constraints (23). In any period $t \geq 1$, the supplier may choose a defect rate from the following subinterval only $p_t \in (0; \tilde{p})$. So one effect of certification is to put a limit on how far the supplier can deviate from the effort expected by the buyer. In (23), $I_{p_{t(\tilde{p})}p}$ is an indicator variable that is equal to 1 when the supplier chooses a lower defect rate (better quality) than required by certification and 0 otherwise. We define $I_{p_{t(\tilde{p})}p}$ as an indicator for when the defect rate chosen is equal to the requirement of certification. Comparing it with Equation (19), we see that the fine is only a factor in the supplier’s incentive compatibility constraint when a quality level better than the certification level is selected by the buyer. When the defect rate target is the certification rate, which is by definition verifiable, there are no fines when defects occur. Equation (23) reveals one of the potential benefits of certification: it can limit the supplier’s benefits from deviating, which relaxes the constraint (20) of DRE, making the buyer better off. Without certification, the right-hand side (r.h.s.) of (21) would be $F_t$. If certification is used, then sometimes the r.h.s. of (21) is $C_S(\tilde{p})$. Define $\tilde{F} = -C_S(\tilde{p})$, if $C_S(\tilde{p}) < F_t$; then certification makes it possible for the buyer to give a smaller incentive to the supplier not to deviate. However, Proposition 5.1 shows that certification does not always give a benefit to the buyer.

**Proposition 5.1.** Necessary conditions for implementing a certification mechanism are $\alpha^{-1}F_S + \alpha L < F^{FB}$ and $C_S(\tilde{p}) < \tilde{F}$. Otherwise DRE dominates CDRE.

Proposition 5.1 is established by two observations. First, the buyer does not need certified suppliers if the first best can be achieved in the dynamic relational equilibrium without certification. Therefore, from Proposition 3.1, certification is used only if $\alpha^{-1}F_S + \alpha L < F^{FB}$. Second, if $C_S(\tilde{p}) > \tilde{F}$, there will be no improvement in constraint (23). Therefore, the certification mechanism is used only if $C_S(\tilde{p}) < \tilde{F}$.

A third way in which certification can fail to add value over DRE is when $\tilde{p} \leq p^{FB}$. This situation implies that certification sets a quality standard that is optimal or higher than optimal for the supply chain. This can happen when a generic standard for multiple industries is all that is available for certification purposes and it meets or exceeds the specific needs of a particular industry. It is possible that $\tilde{p}$ is so expensive to achieve, that is, $C_S(\tilde{p})$ is so high, that the buyer would prefer that the supplier remain uncertified. High production costs cut into the buyer’s profits. On the other hand, it is also possible for there to be $\tilde{p} < p^{FB}$ for which it is more profitable for the buyer to take the better quality that certification is providing, even if it exceeds the first-best quality level. Proposition 5.2 characterizes the optimal contracts when the equilibrium is one in which $p_t = \tilde{p}$.

**Proposition 5.2.** Let $p_t = \tilde{p}$ for all $t \geq 1$ then. (1) If the cost, to the supplier, of termination is high enough, $\alpha^{-1}F_S + \alpha L \geq C_S(\tilde{p})$ and the supplier’s total expected profit is zero. (2) Otherwise (when $\alpha^{-1}F_S + \alpha L < C_S(\tilde{p})$), the supplier’s total expected profit is $R_{s0} = \alpha((C_S(\tilde{p}) - \alpha^{-1}F_S - \alpha L)/(1 - \delta^{\alpha^2})) > 0$. In both cases the payment to the supplier in period 1 is $C_S(\tilde{p})$ and is constant in all periods $t > 1$.

Case (1) in Proposition 5.2 is when the cost of contract termination is high relative to the cost of producing at the required quality level. As a result, the buyer has a lot of leverage over the supplier and can set the terms so that the supplier makes no profit, that is, there are no agency issues. In case (2) the cost of contract termination is not as high for the supplier, so there is the risk that he will take the payment $w_t$ and break the contract. The buyer must pay the supplier more to create an incentive for him to stay with the contract. This enables the supplier to collect rents and achieve
a positive expected profit. Even though the supplier collects rents in this case, they may still be lower than what the supplier would get in the DRE, and thus the buyer could in theory be better off with the certification. When Proposition 5.2 holds, the fine does not play a role because the certification is a binding constraint.

To illustrate, consider a case in which the optimal DRE contract leads to \( p_t = p^\text{FB} \) and \( F_t = F^\text{FB} \) for all \( t \), but the first-best outcome is not achieved. Then we have that \( R_S = \alpha((C(p^\text{FB}) - \alpha^{-1}F^\text{FB} - \alpha L)/(1 - \delta \alpha^2)) \) for the DRE and \( R_S = \alpha((C(p^\text{FB}) - \alpha^{-1}F^\text{FB} - \alpha L)/(1 - \delta \alpha^2)) \) for the CDRE (from part 2 of Proposition 5.2). If \( C_S(p^\text{FB}) < F^\text{FB} \), then CDRE might yet have an advantage over DRE even though it yields a higher quality than wanted by the buyer. The comparison of these two cases illustrates that the question of whether or not the buyer can be better off with certification depends upon the interplay between the cost of producing at the quality level of the certification and upon the differences in agency costs that are driven by the cost of contract termination. The situation described in Proposition 5.2 is just the simplest of three possible equilibrium types in the CDRE. Though more complicated to characterize, the same factors are at work in determining if CDRE dominates DRE. Proposition 5.3 describes three scenarios for the CDRE with \( p > p^\text{FB} \). To the contrary, in the third scenario, the supplier’s compensation is designed to prevent deviation when fines are implemented; the certification is tailored accordingly.

**Proposition 5.3.** Suppose there exists a dynamic relational equilibrium with certification for some \( p > p^\text{FB} \). Then the optimal equilibrium belongs to one of the following three cases.

1. **CDRE1:** The certification defect rate is used in every period, that is, \( p_t = \bar{p} \) for all \( t \geq 1 \), and thus there are no fines as in Proposition 5.2.

2. **CDRE2:** The relationship has three distinct stages. In the initial stage the certification defect rate is used and no fines are imposed. During the second stage, fines are used to drive the defect rate down to levels below that of the certification, and in the third stage the first-best defect rate is achieved. The three stages are defined by two time periods, \( \tau \geq 1 \) and \( T \geq \tau + 1 \), such that \( \tau \geq 1 \) and \( \tau < T \), \( p^\text{FB} < \bar{p} < \tilde{p} \) for \( \tau < T \), and \( p_t = p^\text{FB} \) for \( t \geq T \).

   - (a) If the cost to the supplier of meeting the certification quality level is low enough, that is, \( C_S(\tilde{p}) < \alpha^{-1}F^\text{FB} + \alpha L \), then the buyer does not have to provide excess compensation to the supplier to maintain the relationship and \( R_S = 0 \).

   - (b) If the cost to the supplier of meeting the certification quality level is high enough, that is, \( C_S(\tilde{p}) > \alpha^{-1}F^\text{FB} + \alpha L \), then the buyer must provide excess compensation to the supplier to maintain the relationship, and the supplier has a positive surplus \( R_S = \alpha(C_S(\tilde{p}) - \alpha^{-1}F^\text{FB} - \alpha L)/(1 - \delta \alpha^2)) > 0 \).

   - (c) **CDRE3:** There exists \( \tau \geq 1 \) and \( T \geq \tau + 1 \) such that

\[
p_t = \begin{cases} 
\tilde{p} & 1 \leq t \leq \tau, \\
p^\text{FB} & \tau < t < T, \\
p^\text{FB} & t \geq T,
\end{cases}
\]

and \( R_S = \alpha(\alpha^{-1}F_{t+1} - \alpha^{-1}F^\text{FB} - \alpha L)/(1 - \delta \alpha^2)) \).

Details on how to construct this equilibrium and existence conditions appear in the online appendix.

It follows that when CDRE2 exists, it dominates CDRE1 because for the same total profit provided to the supplier, it is achieving lower defect rates. When certification of quality is possible at some defect rate \( \tilde{p} \), one might think that the buyer will be automatically better off (ignoring the cost of the certification process) because the supplier is forced to deliver at least the certification quality level without the buyer having to provide any incentives. The flaw in this thinking is that the certified defect rate \( \tilde{p} \) is not free for the buyer. The buyer must compensate the supplier for production costs. If these costs are high relative to contract termination costs, there is a threat that the supplier will take the upfront payment and abandon the buyer. So while in the DRE the buyer can gradually decrease \( p_t \), with certification he may have to start at an initially higher level of quality and thus provide stronger incentives to the supplier to not renege early on. These stronger incentives in the form of higher payments later in the contract may make the buyer worse off with certification even if the certification itself is free.

The supply chain expected stage profit for a given defect rate \( p \) is \( \Pi = C_S(p) - C_S(q) - p(q Cl + \bar{q} CE) \), where from the buyer’s FOC we have \( C_S(q) = p(CE - Cl) \). We denote the value of the certification for a given \( \tilde{p} \) as \( V(\tilde{p}) = \max\{V_i(\tilde{p})\} \), where and \( V_i(\tilde{p}) = R^\text{CDREi}(\tilde{p}) - R^\text{DREi} \), \( i \in \{1, 2, 3\} \) and CDREi feasible.

In Figure 3, we plot the value of certification as a function of the certification defect rate, \( \tilde{p} \), for the three equilibria, CDRE1, CDRE2, and CDRE3, for an illustrative example. We use the same parameter values as the base case except set the cost of external detection of a defect, \( CE \), to be 50 CI, so that there is room for improvement over the DRE solution. We see that for each equilibrium, there is a range of defect rates for which there is some potential benefit to the buyer if the supplier can be certified. For CDRE2 and CDRE3 the feasible range begins close to the peak of CDRE1 and CDRE2 dominates CDRE3. Looking at CDRE1, to the left of the peak, the value of certification is decreasing because it is requiring a quality level that is too costly for the buyer. To the right of the peak, the quality level being certified is not high enough to give a large benefit to the buyer. Generally, the ranges over which each equilibrium adds value over the DRE do not necessarily overlap, which means that there is not necessarily a contiguous range of defect rates for which certification adds value.
6. Conclusion
Consumers and regulators in developed countries expect products and the processes used to produce these products to meet high standards for safety, chemical content, pollution, and labor conditions. At the same time buyers (brands) are seeking the lowest cost suppliers in developing countries in which regulation and legal enforcement is weak. Supply chains are complex, and buyers rely on first tier suppliers to make sure their own suppliers are complying with standards, all the while working with razor thin margins. The low profit margins require the buyers to provide upfront working capital to suppliers, thus exposing themselves to some financial risk.

In this paper, we model how financial penalties can be used to create incentives for suppliers to exert effort to achieve compliance, even when these penalties are not legally enforceable. To do this, we use the framework of relational contracts where the supplier’s self-enforcement of penalties is motivated by the threat of contract termination. The potential cost to the supplier of lost revenues while searching for a new partner and the cost of setting up a new relationship deter the supplier from violating the contract terms. However, unless the termination costs are very high, the threat of termination is limited in its ability to motivate the supplier to achieve high levels of compliance. We show that a dynamic contract can artificially increase the termination cost and strengthen the buyer’s hand vis-à-vis the supplier. The dynamic contract appears as if it has a probationary period during which the supplier “proves” itself to the buyer, but this is not what is going on at all. There are multiple ways the supplier can cheat. The dynamic contract structure is working to reduce the supplier’s incentive to cheat in different ways in different stages of the relationship.

We have assumed that the buyer is a well-known brand with commitment credibility. If this were not the case, the formulation of the DRE would require additional constraints to prevent the buyer from deviating from the contract. We found such a formulation intractable but conjecture the following outcomes. Additional constraints on the buyer will of course make him worse off. We expect that the resulting contract would have to have $R_{Bt}$ nondecreasing to provide the buyer an incentive to continue in the relationship. At the same time, the supplier faces less certainty, so we expect him to require higher compensation for any particular level of quality. The net effect will be a reduction in the optimal quality level.

We also model how third-party certification fits into this framework by setting a floor on compliance effort. We show that this can be beneficial to the buyer because it limits the ability of the supplier to deviate from the desired quality levels. At the same time, certification can hurt the buyer’s ability to design optimal dynamic contracts because the certification is inflexible. In a sense, it moves the buyer to a more mature state of the relationship prematurely and undermines the buyer’s ability to increase the supplier’s termination costs.

Greater supplier effort to comply with sustainability goals is not simply a question of increasing payments. The buyer will have to pay for whatever compliance
effort he wants the supplier to exert so that the supplier is not losing money. The challenge for the buyer is to make sure that as much of the payment he makes to the supplier is used on the compliance effort as possible, as opposed to being taken as a rent by the supplier. This is where the contract structure is important. What we have shown is that holding the supplier’s profit low (zero) at the start of the relationship and postponing the supplier’s opportunity for profit to later periods, while steadily ramping up quality expectations, increases the buyer’s leverage and improves quality.

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Endnote


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