Buyer and Nonprofit Levers to Improve Supplier Environmental Performance

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Material IQ (MiQ) is a new decision tool designed by GreenBlue to help suppliers safely share sensitive chemical-toxicity data with their customers. As GreenBlue takes MiQ to market, it must determine under what market conditions to promote the use of MiQ and when to recommend that a buyer use its implementation as an opportunity to work with an existing supplier. We study GreenBlue's problem in two parts. First, we investigate when a buyer can use a wholesale-price premium and/or buyer-supplier cost sharing to improve a supplier's environmental performance. Based on our findings, we then develop insights into GreenBlue's strategy. We model both a single-supplier and a supplier-competition setting. We find that in the single-supplier setting, if the buyer's optimal strategy is to offer the supplier a premium, then he also fully subsidizes her investment cost to build quality. By developing the supplier's capabilities, the buyer can increase the impact of the premium he offers. In the supplier-competition setting, although cost sharing is less effective as a lever, cases can occur in which the buyer chooses to share costs and prevent the incumbent supplier from having to compete. From GreenBlue's perspective, promoting the use of MiQ and cost sharing are often viable strategies when there exists a one-to-one relationship between a buyer and a supplier. However, GreenBlue's strategy becomes more restricted when competition exists between suppliers. Only when the relative market awareness of quality is high and there is a dominant party in the supply chain should GreenBlue recommend the use of MiQ.

Key words: Nonprofit operations management, sustainable operations management, supplier development, environmental quality, game theory

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1. Introduction

GreenBlue is an environmental nonprofit that develops science-based decision tools for industry. Recently, in an effort to increase the transparency of the chemicals and substances used in products and supply chains, GreenBlue created Material IQ (MiQ), a new tool with which suppliers can safely share sensitive chemical-toxicity data with downstream customers without divulging intellectual property secrets. Due to this improved visibility, MiQ can create opportunities for a buyer (i.e., manufacturers and retailers) to work with his supplier to improve her environmental performance. As GreenBlue takes MiQ to market, it must determine under what market conditions to promote the use of MiQ and when to recommend that buyers use the platform as an opportunity to collaborate with suppliers.

MiQ creates transparency between suppliers and buyers through the process by which information is collected and shared within the portal. To add a product's information to MiQ, a supplier provides a sample product to SciVera, a third-party chemical safety assessment provider and GreenBlue partner. SciVera breaks down the chemical composition of the product to a granular level to determine the relative hazards of its components. This information is then entered into MiQ. Within MiQ, a buyer (with access) can then see details regarding the potential hazards of the supplier's product but cannot see enough information to reverse engineer the product. The supplier's intellectual property is protected because MiQ only stores and transmits the data needed to assess a product's environmental performance; SciVera retains the detailed information of the chemical assessment.

MiQ is one of a growing number of tools being developed by nonprofits in order to increase the visibility of environmental practices in supply chains. For example, environmental nonprofits Made Safe and Environmental Working Group both have recently launched new labels to warn consumers of the potential hazards of chemicals found in household products (Joseph 2016). Like MiQ, the labels are meant to address the current gaps in United States law regarding the regulation of chemicals. Similarly, the Sustainable Apparel Coalition has developed the Higg Index, a set of tools with which companies can measure and share their sustainability performance (including material and chemical toxicity) with supply chain partners (Clancy 2013). The improved visibility these tools create can not only improve the flow of information between supply chain partners, it can also uncover opportunities for a buyer to work with a supplier to improve environmental practices.[1]

Our research examines how a buyer can use a wholesale-price premium and/or buyer-supplier cost sharing to improve a supplier's environmental performance, when the performance can be objectively observed by both parties. Based on our findings for a buyer, we then develop insights into GreenBlue's strategy for promoting MiQ. Our objective is to identify ways to increase *the impact of an agreed upon implementation* of a nonprofit tool, such as MiQ, that enables improved visibility of environmental practices in supply chains. Since the MiQ portal can be implemented in either a one-to-one basis between a buyer and a supplier or as a marketplace, where a buyer has access to the information of multiple suppliers, we analyze both a single-supplier and a supplier-competition setting.

To model our problem, we examine a supply chain in which a profit-maximizing buyer (he) attempts to increase the environmental performance (quality) of the product his supplier (she) provides. We generalize our problem to focus on quality, where quality can represent either information or physical attributes; a product with high environmental quality is defined as having a low impact on the environment or human health. Since tools like MiQ can enable not only the development of environmental quality but also its communication to end consumers, we define the market demand for the product as being determined by both price and quality. We assume that while consumers' demand for

[1] Nike is well known for having extensive visibility into its supply chain. Because of this, opportunities exist for Nike to work with its suppliers to improve their environmental practices. For example, in 2009, Nike began to integrate sustainability into its preliminary design and manufacturing decisions. As part of this initiative, Nike implemented a demanding but collaborative environmental program at over 40 of its footwear suppliers in Asia (Plambeck et al. 2012).

a product with higher quality is increasing, consumers expect the price for this product to remain the same (Hyatt and Spicer 2012, Shreeves 2014).

Most of the information shared through MiQ is currently not required by law in the United States, but instead, voluntary. According to James Ewell, Sustainable Materials Director at GreenBlue, a majority of GreenBlue's potential customers are "[manufacturers that] have the leverage of purchasing power but are wholly dependent upon cooperation from their suppliers if they are going to be able to meet their chemical transparency goals" (Ewell 2014). Furthermore, although MiQ makes environmental quality observable, it still may not be possible to measure and argue a supplier's compliance with a quality contract in a court. Hence, we take environmental quality here as noncontractible. The challenge for buyers and nonprofits is to establish effective levers for incentivizing improved environmental quality from suppliers absent of regulation and contracts, and instead, based strictly on market forces. A supplier must see a need to incur costs and invest to improve quality. Since we examine a setting in which a new tool is being introduced to an existing relationship between a buyer and a supplier, our analysis focuses on how the existing division of the supply chain margin between the two parties influences the buyer's, the supplier's, and the nonprofit's decisions.

We analyze the buyer's use of two levers to improve supplier quality: an increase in wholesale price (i.e., a wholesale-price premium) and subsidizing a portion of the supplier's investment cost to build quality (i.e., buyer-supplier cost sharing). We add to the supplier development literature (e.g., Friedl and Wagner 2012, Wang et al. 2010) a model that illustrates and compares the effectiveness of the two levers in improving a supplier's performance under both a single-supplier and a supplier-competition setting. Our buyer results serve as a foundation for determining when and how GreenBlue should promote the implementation of MiQ between a buyer and a supplier. GreenBlue is a pragmatic nonprofit that works with industry to solve environmental problems. Thus, while GreenBlue would like to maximize quality, it will only do so if both buyers *and* suppliers do not incur losses from using MiQ. We contribute to the emerging nonprofit operations-management literature (e.g., DeVericourt and Lobo 2009, Privett and Erhun 2011), an example of how a pragmatic nonprofit can influence the environmental performance of a supply chain based solely on market forces.

Our results demonstrate how the effectiveness of the two levers we model is influenced by the market opportunity, the division of the supply chain margin, and the presence of supplier competition. For example, in the single-supplier setting, the buyer's premium strategy is generally to offer the supplier an increase in wholesale price when she captures a low portion of the supply chain margin and consumers' awareness of quality is high. Furthermore, if the buyer's optimal strategy is to offer the supplier a premium, then he also fully subsidizes her investment cost to build quality. By aggressively investing in the supplier, the buyer develops her capabilities and, as a result, increases the impact of his premium offer. Interestingly, cost sharing can help the buyer to discover opportunities to invest in a low-margin supplier that do not exist when he considers only the premium as a lever to improve quality.

When competition exists between suppliers, although cost sharing tends to be a less effective lever, cases can occur in which the buyer maximizes his profit by working with his incumbent supplier. Specifically, when the second supplier is not competitive on cost, demand is primarily driven by quality, and the supplier's existing margin is low, the buyer chooses to share the cost to build quality and prevent the incumbent supplier from having to compete. For these cases, the buyer may use the wholesale-price premium and cost sharing as complements or substitutes for one another depending on the difference between the supplier's unit cost of quality and the relative market awareness of quality.

Whether GreenBlue should recommend the use of MiQ and cost sharing is highly dependent on whether competition exists between suppliers. For the single-supplier setting, as long as the supplier's portion of the supply chain margin and the relative market awareness of quality are both not too low, GreenBlue should promote the use of MiQ. Furthermore, if the supplier's portion of the supply chain margin is not high, then GreenBlue should also recommend that the buyer collaborate with the supplier to implement MiQ and improve quality. GreenBlue's strategy is more restricted for the supplier-competition setting. Specifically, GreenBlue should only promote the use of MiQ when the relative market awareness of quality is high and there is a dominant player in the supply chain. In addition, it should only recommend buyer-supplier cost sharing when the second supplier is less competitive on cost, demand is primarily driven by quality, and the buyer is the dominant player in the supply chain. Otherwise, GreenBlue should not promote the use of MiQ or cost sharing.

The remainder of the paper is organized as follows. In §2 we review the relevant literature and in §3 we introduce the model formulation. We present our findings regarding the buyer's strategy in §4 and GreenBlue's strategy in §5. In §6 we examine some of our key modeling assumptions. In §7 we discuss our insights and conclude the paper.

2. Literature Review

Next, we discuss three streams of literature relevant to our work: nonprofit operations management, supplier quality investment, and levers for improving suppliers' nonprice performance.

Nonprofit Operations Management: There is a growing body of work that examines nonprofit problems from an operations management (OM) perspective (e.g., DeVericourt and Lobo 2009, Lien et al. 2014, Privett and Erhun 2011; for a review, see Berenguer et al. 2015). Only a few of these works analytically model a nonprofit's activism towards firms (e.g., Chen et al. 2015, Kraft et al. 2013). Instead, most of the papers that analytically examine activism can be found in either the strategy or political economy literatures (e.g., Baron 2001, Calveras et al. 2007, Lenox and Eesley 2009). We add to the OM literature an example of how a nonprofit can work with a buyer to improve the environmental performance of his supply chain. Since proper regulations for managing chemical usage are still not in place in many countries, we do not incorporate regulation into our model. Instead, we focus on a nonprofit's ability to influence a buyer's and a supplier's decisions based solely on market forces.

Within the environmental literature, there exists a division between activists on whether to confront or to work with firms to improve their environmental performance (Dowie 1996, Schwartz and Paul 1992, Speth 2008). Conner and Epstein (2007) divide nonprofits into two broad categories: purists, who seek change through confrontation, and pragmatists, who instead prefer to work with firms to solve environmental problems. GreenBlue regularly works with industry to find solutions to environmental problems. As noted by James Ewell, "GreenBlue has always been 'industry-facing' in its work [and worked to provide] the practical guidance that is necessary for companies to fully engage and implement best practices [in sustainable design]" (Ewell 2014). Thus, we classify GreenBlue as a pragmatic nonprofit and when formulating its objective function to maximize quality, we incorporate constraints to ensure that both the buyer and the supplier do not incur a decrease in profits from using MiQ.

A recent stream of literature uses analytical models to examine the impact third-party eco-labels can have on consumers, firms, and governments decision-making. The range of topics addressed include: the welfare implications of adopting a label (e.g., Bonroy and Constantatos 2014, Bottega and de Freitas 2009), the competition dynamics between nonprofit and either government or industry labels (e.g., Baksi and Bose 2007, Fischer and Lyon 2014, Heyes and Maxwell 2004), and a firm's decision to self-regulate with a label (e.g., Baron 2010, Youssef and Lahmandi-Ayed 2008). We differentiate ourselves within this body of research by addressing how the implementation of such tools can be enhanced by a buyer's use of more collaborative efforts.

Supplier Quality Investment: A supplier's *conformance quality* (e.g., defect-free production rate) and how it can be improved with mechanisms such as recall cost sharing, price rebates, and warranty cost sharing has been well studied in the literature (e.g., Baiman et al. 2000, Balachandran and Radhakrishnan 2005, Chao et al. 2009, Lim 2001, Reyniers and Tapiero 1995, Zhu et al. 2007). These authors primarily assume that quality or the effort to build it is unobservable (i.e., cannot be assessed) unless the product reaches the end consumer or is inspected. Kaya and Özer (2009) study a setting closer to our work; they consider a supplier's *performance quality* (i.e., a demand-enhancing attribute) that is observable but not contractible. The authors assess the "risk" associated with non-contractible quality and asymmetric cost information, where the buyer may or may not commit on the retail price.

The effect of supplier competition on conformance quality and performance quality has been studied in the OM literature. Deng and Elmaghraby (2005) study a "tournament" on conformance quality between the potential suppliers of a buyer. They show that the buyer can attain a higher quality level with competition. Benjaafar et al. (2007) characterize the value of supplier competition on service quality (i.e., performance quality) for a buyer who wants to source a product/service with a fixed price and demand. They compare a supplier-allocation mechanism and a supplier-selection mechanism and find that the effectiveness of the competition type hinges on the cost structure of the suppliers. Similar to Deng and Elmaghraby (2005) and the supplier-selection mechanism in Benjaafar et al. (2007), we model supplier competition as a winner-take-all scenario.

Due in part to improvements in technology (e.g., QR codes and smartphone apps) and to the efforts of entities such as GreenBlue, consumers' knowledge of the environmental quality of the products they purchase continues to improve (Chouinard et al. 2011, Pratt 2015, Revkin 2014). Nevertheless, even with this improved visibility, establishing a quality-based contract may be infeasible. Kaya and Özer (2009, p. 669) cite three specific reasons why performance quality can be difficult to contract on: "First, quality is difficult to measure and verify for a third party such as a court...[second, firms] cannot identify every possible contingency in advance....[and third, OEMs face] time-to-market pressures". Although we assume toxicity is observable in our setting, it may not be possible to measure and argue its compliance with a quality contract in a court. For example, reports have been published on the potential health risks of chemicals (e.g., triclosan, brominated flame retardants (BFRs), and phthalates) found in everyday consumer products such as toothpastes (Kary 2014), furniture (Peeples 2015), and plastic containers (Storrs 2016). Yet these chemicals remain unregulated and widely used by industry. Second, defining all possible contingencies regarding the potential risks to toxicity is often impossible. For example, cases have occurred in which the replacement substances for potentially toxic substances (e.g., bisphenol-S (BPS) replacing bisphenol-A (BPA)) were found to introduce new and unforeseen risks (Bilbrey 2015).

Given this, we model a setting in which a supplier's performance quality is observable but not contractible. Modeling quality as observable aligns with our focus on improving the performance of a tool like MiQ upon implementation. To isolate the effectiveness of each lever and focus on the incentives of each party, we assume complete information. Although our research is motivated by an environmental issue, our model can be applied to a broad set of problems where the quality in question is an attribute that "consumers prefer more to less" (Kaya and Özer 2009, p. 669).

Levers for Improving Suppliers' Nonprice Performance: Within the supply chain contracting literature, a number of papers analyze how a buyer can develop a supplier's capabilities to improve her quality or process in single-supplier (e.g., Corbett and DeCroix 2001, Iyer et al. 2005, Kim and Netessine 2013, Qi et al. 2015) and multi-supplier (e.g., Li 2013, Li and Debo 2009, Tang et al. 2014, Zhu et al. 2007) settings. Although inefficiencies occur in our problem due to the buyer and the supplier making decentralized decisions, as a nonprofit, GreenBlue is not in a position to coordinate the supply chain. Hence, we do not focus on supply chain coordination, but instead assume that a wholesale-price agreement exists between the buyer and the supplier, with the division of the supply chain margin taken as given. We are interested in how the established buyer-supplier relationship impacts the buyer's, the supplier's, and the nonprofit's decisions.

Outside of the contracting literature, there exists a stream of research that utilizes analytical modeling to examine the impact a buyer investing in a supplier's capabilities can have on performance (e.g., Babich 2010, Friedl and Wagner 2012, Kim 2000, Liu et al. 2010, Talluri et al. 2010, Wang et al. 2010, 2014). While many of these works address the interaction effects that can occur between different incentive mechanisms (e.g., quantity allocation and sharing costs), they do not consider the impact a buyer's sharing of a supplier's investment cost can have on his use of a wholesale-price premium. Structurally, the work that most relates to ours is Wang et al. (2010). The authors study a setting in which a buyer can either source from multiple suppliers and/or exert effort to improve supplier reliability. Although the authors consider a dual-sourcing scenario, their focus is on the random yield/capacity of the suppliers, and not the potential competition that can occur between suppliers.

There is an emerging body of work within the supply chain literature that investigates corporate social responsibility (CSR). One aspect that makes CSR a challenging topic to study is that CSR activities are often nonverifiable (Norman and MacDonald 2004) and therefore are difficult to enforce with contracts. As a result, papers have emerged that examine the impact that sourcing strategies can have on a supplier's CSR performance (e.g., Agrawal and Lee 2015, Guo et al. 2015, Hendrikse and Letizia 2016, Mendoza and Clemen 2013). For example, Guo et al. (2015) consider the sourcing decisions of a buyer choosing between responsible and risky suppliers. The authors examine how supplier concentration influences a buyer's responsible sourcing decisions. Mendoza and Clemen (2013) examine a setting with two competing buyers who can source from separate suppliers or a shared supplier. The authors consider cases where the buyers can help to improve the supplier's sustainability performance. Although these works examine how a buyer-supplier relationship can improve the social-responsibility performance of a supply chain, they do not consider the impact of supplier competition.

Our research contributes to the OM literature a model that examines and compares the effectiveness of a wholesale-price premium and cost sharing in improving a supplier's environmental performance. We examine both a single-supplier model and a supplier-competition model. We consider our problem from both a buyer and a social-good perspective.

3. The Model

Next, we review our model formulation and assumptions. We first discuss the single-supplier model and then we introduce the supplier-competition model.

Single Supplier: We consider a single-buyer, single-supplier model, where both parties are profit maximizing. The buyer sells a product with demand driven by both price and environmental quality. The supplier produces the product and thus determines its quality. Based on market trends, we assume that consumers demand a higher environmental-quality product, but not at a higher price (Hyatt and Spicer 2012, Shreeves 2014). Hence, we fix the retail price of the product, but allow demand to vary based on quality. The consumer demand for the product is given by

$$D = K - ap + dq, \tag{1}$$

where K is the intrinsic market potential, $a > 0$ is consumers' price awareness, and $d > 0$ is consumers' environmental quality awareness. Retail price p is fixed with only environmental quality, q, being a decision variable for the supplier. We model the buyer's demand as linear in both price and quality, with demand decreasing in price but increasing in environmental quality.[2] The linear demand form has been widely used to represent consumer demand when studying the interactions between supply chain partners (e.g., Kaya and Özer 2009, Savaskan and Van Wassenhove 2004, Tsay and Agrawal 2004). The structure is suitable for our purposes since it helps us to isolate the effect that the division of the supply chain margin has on each party's decision(s).

Since we examine a setting in which a new tool is introduced to an existing relationship between a buyer and a supplier, we assume that the buyer and the supplier already have an existing wholesale-price agreement in place for the product. Our analysis focuses on the buyer's, the supplier's, and GreenBlue's decisions given the existing division of the supply chain margin between the buyer and the supplier. The two levers available to the buyer for improving quality are to offer the supplier a wholesale-price premium to offset her unit cost of quality and/or to share her investment cost to build quality.[3] The modeling of the premium is not based on MiQ functionality; we include the premium in our analysis because it is a commonly used incentive for improving a supplier's performance.

The buyer's (B) profit function for the single supplier model (subscript S) is given by

$$\pi_S^B = (K - ap + dq)[(p - \omega) - \overline{\omega}] - \gamma y q^2. \tag{2}$$

Here $p - \omega$ represents the buyer's existing margin and $\overline{\omega}$ is the per-unit premium the buyer offers the supplier in order to increase her environmental-quality level. To capture that the quality the supplier provides is voluntary, we model the premium as being independent of the quality level the supplier delivers and as being offered before the supplier decides on q.[4] Also for this reason, we assume that the buyer can only increase the wholesale price he pays the supplier; i.e., $\overline{\omega} \geq 0$. The γ term represents the portion of the supplier's investment cost the buyer is willing to incur, with $0 \leq \gamma \leq 1$. If $\gamma = 0$, then the buyer does not share costs with the supplier.

After the buyer determines the premium and the cost-sharing portion that he is willing to offer, the supplier (superscript S) sets the quality level, q, to maximize her own profit function given by

$$\Pi_S^S = (K - ap + dq)[(\omega - m) + (\overline{\omega} - cq)] - (1 - \gamma) y q^2. \tag{3}$$

[2] We model demand as increasing in quality due to recent trends regarding "green" chemicals. For example, a recent report commissioned by the American Sustainable Business Council and the Green Chemistry & Commerce Council found that consumer preferences for "green chemicals" is increasing rapidly. Over the next 10 years, the demand for green chemicals is expected to grow 24 times as much as the market for conventional chemicals (Bernstein 2015).

[3] A buyer could be hesitant to share costs with a common supplier. By developing a supplier's capabilities, the buyer may generate benefits that permeate to potential competitors, who in turn may invest in improving the performance of their own suppliers or may instead free ride on the buyer's investment. This dilemma is similar to a public-goods game where participants privately make investments in a public pot that is then shared among all participants. We ignore the potential public-good and free-riding questions that could exist if a buyer were to develop the capabilities of a common supplier. Including these aspects, while potentially insightful, would add significant complexity to our model.

[4] Many products contain legal amounts of toxic and potentially toxic substances. As a result, a divide often exists between industries, activists, and regulators regarding what is the "right level" of toxicity and how does level of exposure influence toxicity (Dale-Harris 2014). In an environment such as this, it can be difficult for a buyer and a supplier to agree upon a wholesale-price premium contingent on the environmental performance of a product.

Here $\omega - m$ represents the supplier's existing margin and cq is the supplier's additional unit cost of quality. Term yq^2 is the supplier's investment cost to build quality, q, with the supplier paying portion $1-\gamma$. We model the investment cost as a quadratic function. Thus, our assumption is that the effort to improve quality has diminishing returns (see Savaskan and Van Wassenhove 2006, p. 242). Since quality is observable in our setting (due to the presence of MiQ), we assume that the supplier invests truthfully and does not try to hide or falsify her investment (see e.g., Plambeck and Taylor 2016).

The sequence of events for the single-supplier model is as follows:

(i) The buyer determines the portion of the supplier's investment cost that he is willing to share to improve her ability to build quality.

(ii) The buyer offers the supplier the wholesale-price premium that he is willing to pay to entice her to invest in environmental quality.

(iii) The supplier sets her quality level based on the cost-sharing portion, premium, consumers' environmental-quality awareness, and her cost structure.

(iv) The buyer and the supplier earn their profits based on the market demand, the supplier's quality choice, and the buyer's cost-sharing and premium choices.

In both of our models, we set the buyer as acting before the supplier in our sequence of events. This is done to capture (1) the voluntary participation of the supplier to improve quality, and (2) the need for the buyer, as the direct beneficiary of an improvement in quality, to entice the supplier to invest.

Supplier Competition: According to James Ewell, MiQ was originally designed to act as a "marketplace", where buyers and suppliers in an industry could freely share chemical composition information (Ewell 2014). Under a marketplace design, a buyer would have access to not only his own suppliers' data, but also to the data of suppliers across the industry. This arrangement encourages competition between suppliers to demonstrate their environmental performance. To examine how competition impacts the buyer's and suppliers' decisions, we examine a supplier-competition setting.[5] The model is similar to the single-supplier model, but with the buyer considering sourcing from a different supplier. The new supplier is identical to the incumbent supplier except that her unit cost of quality is higher than the incumbent supplier's unit cost; i.e., $c_2 > c_1$ with $c_1 \equiv c$ in the single-supplier model.[6]

We assume that the buyer is only willing to share costs with the incumbent supplier with whom he has an established relationship. This assumption is inline with the MiQ marketplace concept, where buyers have an opportunity to support their existing suppliers joining the marketplace. The buyer's

[5] Outside of the contracting literature, models that examine how supplier competition can impact a supplier's nonprice performance have been applied to a broad range of OM topics including supply disruption risk (e.g., Babich 2006, Babich et al. 2007), yield uncertainty (e.g., Federgruen and Yang 2009, Tang and Kouvelis 2011), service (e.g., Cachon and Zhang 2007, Ha et al. 2003), and quality (e.g., Benjaafar et al. 2007, Gans 2002).

[6] We assume that the suppliers have the same existing margin, $\omega - m$. Introducing a second supplier with a different existing margin would only complicate the analysis without adding to our insights.

and supplier 1's profit functions therefore match Equations (2) and (3). Supplier 2's profit function (i.e., the new supplier) if she wins the competition (subscript C) is then

$$\Pi_C^{S_2} = (K - ap + dq_2)[(\omega - m) + (\overline{\omega} - c_2 q_2)] - yq_2^2. \tag{4}$$

The sequence of events for the supplier-competition model is as follows. First, the buyer decides the portion of the incumbent supplier's investment cost that he is willing to share. Second, he decides the per-unit premium that he is willing to pay the winner of the competition to offset her unit cost of quality. Third, the two suppliers compete in a static game of complete information; i.e., they make their quality proposals simultaneously without observing each other's actions. Supplier i's strategy is to set environmental quality level q_i. After the two suppliers compete, the buyer then sources from the supplier with the highest quality level. The winning supplier earns the buyer's entire business and incurs the related quality costs.[7]

Our supplier-competition model is based on fundamental aspects of Benjaafar et al. (2007) and Jiang and Wang (2010). Similar to the supplier-selection model found in Benjaafar et al. (2007), we consider a winner-take-all scenario where the buyer only sources from one supplier and does not split his demand between suppliers. In Benjaafar et al. (2007), the higher a supplier's quality, the higher the probability she captures the demand. We simplify this assumption and allocate the full demand to the supplier with the highest quality. Similar to Jiang and Wang (2010), we consider the suppliers' cost difference as the measure of competitive intensity, with the competition strengthening as the difference decreases. In this regard, the competitor is only used to incentivize the existing supplier to increase her effort. Our focus is not on which supplier wins the competition, but instead, on how the presence of competition impacts the incumbent supplier's quality decision. Our model is designed to capture the influence that the MiQ marketplace can have on an existing supplier's environmental performance.

Next, we analyze our problem by characterizing the subgame perfect Nash equilibrium for each model. By backwards induction we solve for the supplier's quality response, the buyer's choice of premium, the buyer's cost-sharing portion, and the resulting profits. See Appendix A for the equilibrium derivations and results; see Tables A.2 and A.4 for the closed-form expressions for the supplier's quality choice and the buyer's premium choice for each model. Results found in the appendix and the online appendix are referenced as A.x and O.x here. We augment our analysis with a numerical study; the results are cited throughout the main text and the details of the analysis can be found in Appendix C. For reference, Table 1 summarizes our notation.

[7] Recent examples can be found of proactive industry leaders investing in their suppliers' environmental and social-responsibility practices, even though they may not always source from these suppliers. Take, for example, Nike (www.nikeresponsibility.com/report/content/chapter/manufacturing). Nike regularly works with suppliers to ensure they maintain proper practices. Nike's rationale for doing so is that these efforts will not only improve the environmental and social-responsibility performance of Nike's own supply chain, but also create change within the apparel industry.

Table 1 Notation

Decision Variables	
$\overline{\omega}_i$	Wholesale-price unit premium paid by the buyer to the supplier; $\overline{\omega}_i \geq 0$ and $i \in \{S, C\}$
γ_i	Portion of the supplier's investment cost the buyer is willing to share; $0 \leq \gamma_i \leq 1$ and $i \in \{S, C\}$
q_i	Environmental-quality level produced by the supplier; $q_i \geq 0$ and $i \in \{S, C\}$
Demand Parameters	
K	Intrinsic market potential
a	Consumers' price awareness effect on demand; $a > 0$
p	Buyer's retail price; $p > 0$
d	Consumers' environmental quality awareness effect on demand; $d > 0$
Cost Parameters	
ω	Current unit wholesale price paid by the buyer to the supplier; $\omega > 0$
m	Supplier's unit manufacturing cost (before investing in quality); $m \geq 0$
c	Quality-driven unit cost increase to supplier (c_1 in the competition model); $c > 0$
c_2	Quality-driven unit cost increase to second supplier (competition model only); $c_2 > c_1$
y	Supplier's investment cost factor to build quality q; $y > 0$
Consolidated Terms	
θ	Base market potential; $\theta = K - ap$ with $\theta > 0$
$\hat{p}$	Buyer's existing margin (before investing in a premium); $\hat{p} = p - \omega$ with $\hat{p} > 0$
$\hat{\omega}$	Supplier's existing margin (before investing in quality); $\hat{\omega} = \omega - m$ with $\hat{\omega} > 0$

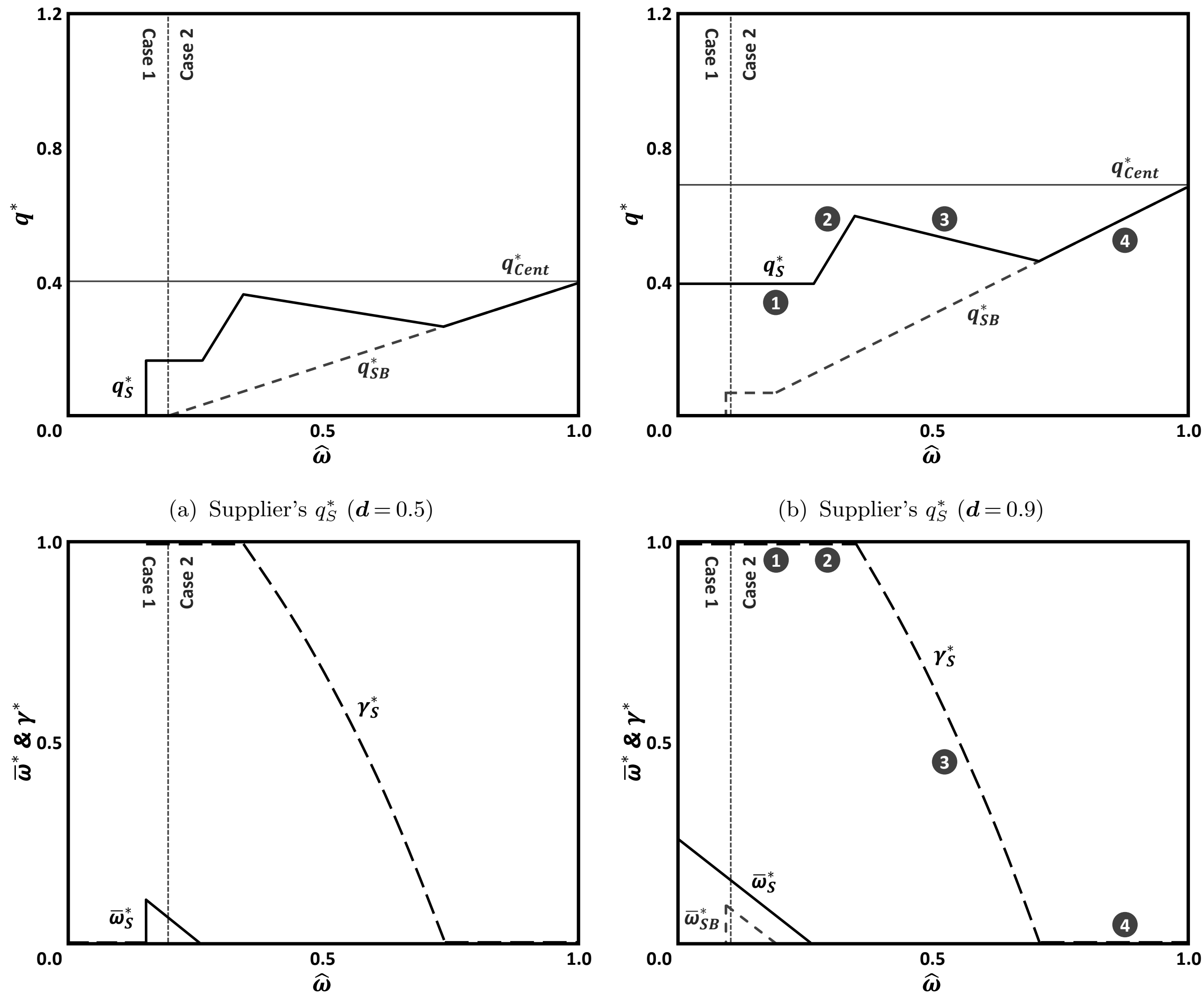
4. The Buyer's Strategy

We divide our analysis of the buyer's strategy for improving supplier quality into two subsections. First, we study the single-supplier model and then we analyze the supplier-competition model. For both settings we focus our discussion on the quality outcomes from the buyer's and the supplier's decisions. Understanding these outcomes establishes a foundation for examining when and how GreenBlue should promote the use of MiQ in §5.

To simplify our notation, we define $\theta \equiv K - ap$ (base market potential), $\hat{p} \equiv p - \omega$ (buyer's existing margin), and $\hat{\omega} \equiv \omega - m$ (supplier's existing margin). In the appendices, we present general results for $\hat{p}$ and $\hat{\omega}$, with $\hat{p} + \hat{\omega}$ fixed. To show how the division of the supply chain margin between the buyer and the supplier impacts our findings, in our numerical illustrations we set the total supply chain margin to 1 with $p = 1$ and $m = 0$. Hereafter, references to the buyer's or the supplier's margins are with respect to their existing margins before any investments are made; references to the buyer's choice of premium or the supplier's choice of quality are with respect to equilibrium values unless otherwise stated.

4.1. Single Supplier

Following our backward induction solution method, we first present the supplier's quality decision and then discuss the buyer's premium and cost-sharing decisions. Figure 1 illustrates the buyer's and the supplier's equilibrium decisions and is referenced throughout §4.1. Figures 1(a) and 1(b) demonstrate the supplier equilibrium quality level, q_S^*, with respect to the supplier's existing portion of the supply chain margin, $\hat{\omega}$. Figures 1(c) and 1(d) show the buyer's choice of premium, $\overline{\omega}_S^*$, and cost-sharing portion, γ_S^*, with respect to $\hat{\omega}$. To show how cost sharing influences both the buyer's and the supplier's



(a) Supplier's q^*_S ($\boldsymbol{d}=0.5$)

(b) Supplier's q^*_S ($\boldsymbol{d}=0.9$)

(c) Buyer's $\overline{\omega}^*_S$ and γ^*_S ($\boldsymbol{d}=0.5$)

(d) Buyer's $\overline{\omega}^*_S$ and γ^*_S ($\boldsymbol{d}=0.9$)

Figure 1 Single Supplier: Environmental Quality with Respect to the Supplier's Existing Margin

Note: The following values were used to generate Figure 1, $K = 1.00$, $a = 0.50$, $p = 1.00$, $m = 0.00$, $y = 0.40$, and $c = 0.20$. Case 1 (Case 2) represents when the supplier does (does not) require a premium to invest in environmental quality. Terms q^*_{SB} and $\overline{\omega}^*_{SB}$ denote the base case equilibrium quality and premium levels for when cost sharing is not an option for the buyer. The numbering in Figures 1(b) and 1(d) corresponds to the description of the figures in the text on pages 14 and 15.

decision making, we include the equilibrium quality level and premium (i.e., q^*_{SB} and $\overline{\omega}^*_{SB}$) for a base case in which the buyer does not consider cost sharing as a lever to improve quality. For comparison purposes, in our graphs we include the optimal quality level for the centralized solution, q^*_{Cent}, and present both a low (i.e., $d = 0.5$) and a high (i.e., $d = 0.9$) consumer environmental-quality awareness.

Proposition 1 demonstrates the conditions under which the supplier requires a premium to invest in quality and the buyer utilizes a premium and cost sharing to encourage quality investment. We divide the proposition into three parts. First, we consider the supplier's best response; then we analyze the buyer's premium and cost sharing decisions.

Proposition 1.A. *[Supplier] If $\frac{d}{\theta} < \frac{c}{\hat{\omega}}$ (Case 1), then the supplier requires a premium to invest in quality; otherwise, if $\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$ (Case 2), then she always invests in quality, with or without a premium. This result is independent of the buyer's cost-sharing decision, γ. The supplier's best response for a* *given premium* $\overline{\omega}$ *and a given* γ *is* $q_S^*(\gamma,\overline{\omega}) = \left(\frac{d(\hat{\omega}+\overline{\omega})-c\theta}{2(cd+(1-\gamma)y)}\right)^+$.

Whether the supplier requires a premium to invest in quality hinges on the tradeoff between the relative market awareness of quality (i.e., $\frac{d}{\theta}$) and the supplier's unit cost impact of quality (i.e., $\frac{c}{\hat{\omega}}$). When the supplier's portion of the supply chain margin is low (i.e., Case 1), she only invests in quality if the buyer increases her margin by offering her a wholesale-price premium. As shown in Figures 1(a) and 1(c), $q_S^* > 0$ only when $\overline{\omega}_S^* > 0$ under Case 1. Without a premium from the buyer, the supplier's existing margin, $\hat{\omega}$, is too low (for the given market opportunity) to justify her investment to improve quality. Observe that as shown in Figure 1(b), Case 1 is restricted to even lower values of $\hat{\omega}$ as consumers' environmental quality awareness, d, increases. For higher values of $\hat{\omega}$ (i.e., Case 2), the market opportunity outweighs the supplier's unit cost impact of quality, so she can justify investment, even if the buyer does not offer to support her with a premium.

Next, Proposition 1.B defines when the buyer utilizes a premium to increase the supplier's quality for a given γ. See Appendix A and Table A.2 for the buyer's equilibrium premium for a given γ.

PROPOSITION 1.B. *[Buyer] For a given* γ*, the buyer offers the supplier a premium to invest in quality when:*
(i) Case 1 ($\frac{d}{\theta} < \frac{c}{\hat{\omega}}$)*:* $d^4(\hat{p}+\hat{\omega})^2 + \theta^2[(cd+2y(1-\gamma))^2 - 4cdy\gamma] \geq 2d^2\theta[(\hat{p}-\hat{\omega})(cd+2y) + 2\hat{p}(cd-y\gamma)]$ *and* $\hat{p}+\hat{\omega} \geq \frac{\theta(3cd+2y(1-\gamma))}{d^2}$.
(ii) Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$)*:* $d^2[cd(\hat{p}-\hat{\omega}) + y(\hat{p}(1-\gamma)-\hat{\omega})] \geq \theta[c^2d^2 + cdy(3-4\gamma) + 2y^2(1-\gamma)^2]$.
Furthermore, if the buyer offers the supplier a premium, then the premium is decreasing in the supplier's existing margin, $\hat{\omega}$*, with the resulting quality level independent of* $\hat{\omega}$*.*

When deciding whether or not to increase the wholesale price, the buyer faces a tradeoff between a potential market opportunity and reducing his margin. For both cases in Proposition 1.B, the buyer's decision depends on the difference between his and the supplier's existing margins; i.e., $\hat{p}-\hat{\omega}$. First, consider Case 1, when the supplier does not invest in quality unless the buyer offers a premium. The supplier's low margin under Case 1 does not guarantee that the buyer will offer her a premium. The size of the premium that the buyer must offer the supplier to incentivize her to invest in quality increases as $\hat{\omega}$ decreases. Thus, cases can occur when $\hat{\omega}$ is very low (and thus, $\hat{p}-\hat{\omega}$ is very high) in which the buyer does not offer the supplier a premium when she needs it most.

Second, consider Case 2, when the supplier invests in quality with or without a premium from the buyer. The buyer must decide whether to further encourage investment by offering the supplier a premium versus leaving the supplier to invest on her own. The supplier's willingness to invest in quality is increasing in $\hat{\omega}$. By Proposition 1.B(ii), the buyer's willingness to offer the supplier a premium is limited to cases in which his existing margin is sufficiently larger than the supplier's (i.e., $\hat{p}-\hat{\omega}$ is sufficiently large) and a market opportunity exists (i.e., d is high). Therefore, the buyer offers the supplier a premium only when $\hat{\omega}$ is low and less than $\hat{p}$ under Case 2.

Finally, Proposition 1.C defines the buyer's optimal premium and cost-sharing strategy. Graphically, the buyer offers the supplier a premium for any range of the supplier's margin in which $q_S^* > 0$ and constant in $\hat{\omega}$. Hence, the range of $\hat{\omega}$ values in which $q_S^* > 0$ and constant in $\hat{\omega}$ in Figure 1(a) (1(b)) match with the range of $\hat{\omega}$ values in Figure 1(c) (1(d)) in which $\overline{\omega}_S^* > 0$. For the buyer's cost-sharing strategy, intuition would suggest that the buyer should use cost sharing in place of a premium. However, we find that when the supplier's existing margin is low and consumers' awareness to quality is high, the buyer's profit-maximizing strategy is to instead use them in combination with one another.

PROPOSITION 1.C. *[Buyer] The buyer's optimal premium and cost-sharing strategy is*

(i) Case 1 ($\frac{d}{\theta} < \frac{c}{\hat{\omega}}$): Offers a premium ($\overline{\omega}_S^* > 0$) and fully subsidizes the supplier's investment ($\gamma_S^* = 1$) if and only if $\frac{d}{\theta} \geq \frac{3c}{\hat{p}+\hat{\omega}}$ and $d\,[d^2(\hat{p}+\hat{\omega})^2 + c^2\theta^2] \geq 4\theta y(c\theta - d\hat{\omega}) + 2cd^2\theta(3\hat{p} - \hat{\omega})$. Otherwise, he does not offer a premium ($\overline{\omega}_S^* = 0$) and he does not subsidize the supplier's investment cost ($\gamma_S^* = 0$).

(ii) Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$): Offers a premium ($\overline{\omega}_S^* > 0$) and fully subsidizes the supplier's investment ($\gamma_S^* = 1$) if $\hat{p} \geq \frac{(d\hat{\omega}-c\theta)(cd+y)+2c^2d\theta}{cd^2}$. Otherwise, he does not offer a premium ($\overline{\omega}_S^* = 0$) and his cost-sharing strategy is as follows:

$$\gamma_S^* = \begin{cases} 1 & if \quad X \geq \frac{cd+2y}{cd} \\ (0,1) & if \quad \frac{cd+2y}{cd} > X > 1 \\ 0 & if \quad 1 \geq X \end{cases}$$

with $X = \frac{2d\hat{p}}{d\hat{\omega}-c\theta}$. See Appendix A and Table A.3 for a summary of the conditions for Proposition 1.C. Note that for Proposition 1.C(ii), when $\overline{\omega}_S^* = 0$, if $d\hat{\omega} = c\theta$, then $\gamma_S^* = 1$.

For both Case 1 and Case 2, if the buyer's optimal strategy is to offer a premium, then he also fully subsidizes the supplier's investment cost.[8] Corollary 1 further illustrates Proposition 1.C by defining sufficient conditions such that the buyer offers $\overline{\omega}_S^* > 0$ and $\gamma_S^* = 1$ for both Case 1 and Case 2.

COROLLARY 1. *The buyer offers the supplier a premium and fully subsidizes her investment cost if*

(i) Case 1 ($\frac{d}{\theta} < \frac{c}{\hat{\omega}}$): $\frac{d}{\theta} \geq \frac{3c}{\hat{p}+\hat{\omega}}$ and $\hat{p} - \hat{\omega}\left(\frac{cd+2y}{3cd}\right) \leq \frac{\theta(5cd-2y)}{3d^2}$.

(ii) Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$): $\hat{p} - \hat{\omega}\left(\frac{cd+y}{cd}\right) \geq \frac{\theta(cd-y)}{d^2}$.

Furthermore, under Case 2, the buyer does not subsidize the supplier's investment cost if $\hat{\omega} \geq 2\hat{p} + \frac{c\theta}{d}$.

First, consider Case 1 in Proposition 1.C(i) and Corollary 1(i), when the supplier does not invest in quality unless the buyer offers a premium. The buyer maximizes his profit by one of two strategies: either offer a premium and fully subsidize the supplier's investment cost *or* do not offer a premium and do not subsidize her investment cost.[9] When $\hat{\omega}$ is very low, similar to our findings for the given γ

[8] The buyer determines γ before deciding on $\overline{\omega}$. Since the buyer makes these two decisions sequentially, the equilibrium outcome is identical if instead γ and $\overline{\omega}$ are determined simultaneously or in reverse order.

[9] Under Case 1, $q_S^* > 0$ if and only if $\overline{\omega}_S^* > 0$. The buyer's cost-sharing strategy does not influence the supplier's equilibrium quality when $\overline{\omega}_S^* = 0$.

case (Proposition 1.B(i)), there can be a misalignment of incentives as the buyer may find it too costly to support the supplier when she needs it most and as shown in Figures 1(a) and 1(c), $q_S^* = 0$ when $\overline{\omega}_S^* = 0$. For higher values of either $\hat{\omega}$ or d (under Case 1), if the buyer's strategy is to offer the supplier a premium, then he also sets $\gamma^* = 1$ and fully subsidizes the supplier's investment cost (Corollary 1(i)). By sharing costs, the buyer reduces the supplier's investment cost, develops her ability to improve quality, and thus increases the impact of his premium offer.

Interestingly, as shown in Figures 1(b) and 1(d), under Case 1 the buyer is more willing to offer a premium to a lower-margin supplier when he can share costs. That is, cases occur for low $\hat{\omega}$ values in which, $\overline{\omega}_S^* > 0$ and $q_S^* > 0$, but $\overline{\omega}_{SB}^* = 0$ and $q_{SB}^* = 0$.

LEMMA 1. *Define $\hat{\omega}_S^{min}$ ($\hat{\omega}_{SB}^{min}$) as the minimum supplier margin for which the buyer offers the supplier a premium under the single-supplier, cost sharing (base case) setting. Under Case 1, if the buyer offers the supplier a premium, then $\hat{\omega}_S^{min} \leq \hat{\omega}_{SB}^{min}$.*

Lemma 1 highlights the potential benefits a buyer can incur by developing his supplier's capabilities. Cost sharing helps the buyer to uncover opportunities to use a premium to increase demand with a low-margin supplier that do not exist when cost sharing is not considered as a lever to incentivize supplier performance. This result is somewhat counterintuitive given that the buyer already incurs a portion of the supplier's investment cost under cost sharing.

Numerically we examine whether the buyer increases or decreases his premium offer when he shares costs. We find that for both Cases 1 and 2, whether $\overline{\omega}_S^*$ is greater than or less than $\overline{\omega}_{SB}^*$ depends on the comparative difference between the supplier's unit cost impact of quality, $\frac{c}{\hat{\omega}}$, and the relative market awareness of quality, $\frac{d}{\theta}$. When $\frac{c}{\hat{\omega}}$ is lower relative to $\frac{d}{\theta}$, the supplier requires less of an incentive to invest in quality. Thus, the buyer uses cost sharing to reduce the size of his premium offer; i.e., $\overline{\omega}_S^* < \overline{\omega}_{SB}^*$. Conversely, when $\frac{c}{\hat{\omega}}$ is comparable to $\frac{d}{\theta}$, quality is more costly for the supplier. Cost sharing helps the buyer to reduce the supplier's investment cost and still ensure a high q_S^* with a higher premium offer; i.e., $\overline{\omega}_S^* > \overline{\omega}_{SB}^*$ (see Figure 1(d)). Finally, when $\frac{c}{\hat{\omega}}$ is higher relative to $\frac{d}{\theta}$, the buyer is less likely to offer a premium under both cases (and in particular, the base case).

Next, consider Case 2 in Proposition 1.C(ii) and Corollary 1(ii), when the supplier invests in quality with or without a premium from the buyer. By Corollary 1(ii), the buyer offers the supplier a premium if his existing margin is sufficiently larger than hers and a market opportunity exists (i.e., $\hat{p} - \hat{\omega}\left(\frac{cd+y}{cd}\right) \geq \frac{\theta(cd-y)}{d^2}$). Thus, as shown in Figures 1(a) and 1(b), and similar to our findings for the given γ case (i.e., Proposition 1.B(ii)), the buyer offers the supplier a premium only when $\hat{\omega}$ is low under Case 2.

Under Case 2, the buyer's optimal cost-sharing investment may be to fully (i.e., $\gamma_S^* = 1$), partially (i.e., $0 < \gamma_S^* < 1$), or not (i.e., $\gamma_S^* = 0$) subsidize the supplier's quality investment. Figures 1(b) and 1(d) provide a numerical illustration of the four equilibrium strategy combinations that are discussed in Proposition 1.C(ii). Consider the four ranges of $\hat{\omega}$ values labeled in Figures 1(b) and 1(d). (1) For low $\hat{\omega}$ values, similar to Case 1, if the buyer's strategy is to continue to offer the supplier a premium, then he also continues to fully subsidize her investment cost. (2) As the supplier's margin increases, however, the buyer no longer offers to increase the wholesale price. Instead, he only fully subsidizes her investment cost. Still, the supplier's higher margin (relative to the previous case) along with $\gamma_S^* = 1$ ensure that q_S^* is nondecreasing in $\hat{\omega}$. Within this range, cost sharing is at its most effective in increasing the supplier's quality. (3) For higher values of $\hat{\omega}$, the supplier's larger existing margin causes the buyer to decrease his portion of the shared investment cost. As shown in Figure 1(d), γ_S^* is decreasing in $\hat{\omega}$ and as a result, q_S^* is nonincreasing in $\hat{\omega}$. (4) Finally, when $\hat{\omega}$ is very high, the supplier captures most of the supply chain margin and thus, the buyer does not subsidize her investment cost; i.e., $\gamma_S^* = 0$ and $q_S^* = q_{SB}^*$. This case occurs only if the supplier's existing margin is more than twice the buyer's existing margin (Corollary 1). See Table A.5 in Appendix C.1 for further illustration of Proposition 1.C.

Finally, observe that the quality level for both cases is never greater than the centralized solution; i.e., $q_{SB}^* \leq q_S^* \leq q_{Cent}^*$ (see Lemma A.3 in Appendix B). The buyer makes his cost-sharing decision along with his premium decision to maximize his profit, not necessarily quality.

4.2. Supplier Competition

Next we analyze the supplier-competition model. Recall that the competition sequence of events is as follows. After the buyer offers cost-sharing portion $\gamma_C \in [0,1]$ (to the incumbent supplier) and premium $\overline{\omega}_C \geq 0$ (to both suppliers), the two suppliers simultaneously propose their quality levels. The buyer then sources from the supplier with the highest quality. In our model, since the incumbent supplier has a lower cost, she always earns the buyer's business. The intent of our design is to see how the presence of competition between suppliers impacts the incumbent supplier's quality investment. In this regard, our design is analogous to the buyer setting an environmental standard for the supplier.

We first consider the supplier's best response. Lemma 2 illustrates the two aspects which drive the supplier best-response quality decision in the competition stage.

LEMMA 2. *The supplier best response for a given $\overline{\omega}$ and a given γ is $q_C^* = max(\bar{q}_2, q_1^*)$, with*

$$\bar{q}_2 = \frac{\sqrt{(d(\hat{\omega}+\overline{\omega})+c_2\theta)^2+4y\theta(\hat{\omega}+\overline{\omega})}+d(\hat{\omega}+\overline{\omega})-c_2\theta}{2(c_2 d+y)} \quad \& \quad q_1^* = \left(\frac{d(\hat{\omega}+\overline{\omega})-c_1\theta}{2(c_1 d+y(1-\gamma))}\right)^+.$$

Term $\bar{q}_2$ is the maximum quality supplier 2 can achieve without incurring a profit less than zero; q_1^* is the incumbent supplier's profit-maximizing quality when she does not have to compete with supplier 2.

The incumbent supplier's equilibrium quality level follows from one of two cases. First, when $\bar{q}_2 > q_1^*$, competition drives the incumbent supplier's equilibrium quality level. Specifically, the second supplier is competitive on cost and, as a result, the incumbent supplier's quality is equal to the maximum quality supplier 2 can achieve without incurring a loss in profit. The incumbent supplier invests in a sufficient quality level such that supplier 2 no longer invests. Second, when $q_1^* > \bar{q}_2$, competition does not influence the incumbent supplier's quality level. Instead, she invests in her profit-maximizing quality without considering the presence of the second supplier. We refer to these two cases throughout §4.2. As will be shown, instances can occur in which the buyer uses cost sharing to ensure $q_1^* > \bar{q}_2$. Finally, observe that by inspection of Lemma 2, $q_C^* > 0$ always since $\bar{q}_2 > 0$ always holds. Given the design of our competition model, there always exists sufficient pressure such that the incumbent supplier is forced to make a positive investment in quality.

To determine when competition and/or the incentives the buyer offers drive the supplier's investment, we first identify sufficient conditions such that either (i) competition has no effect on the incumbent supplier's quality or (ii) competition influences the incumbent supplier's quality.

LEMMA 3. *(i) If* $\frac{(c_2-c_1)(d^2\hat{\omega}+\theta y)}{c_1 d+y} \geq Z_1 + \max\left\{0, \frac{2y\theta\hat{p}}{d\hat{\omega}+c_2\theta} - \frac{d\hat{p}[d(c_2-2c_1)-y]}{c_1 d+y}\right\}$*, then competition has no effect on the incumbent supplier's quality proposal and the equilibrium quality.*

(ii) If $Z_1 \geq \frac{d\hat{\omega}[d(c_2-c_1)+y]-\theta y c_1}{c_1 d}$ *and* $Z_2 \geq \frac{(d\hat{\omega}+d\hat{p})[d(c_2-c_1)+y]-\theta y c_1}{c_1 d}$*, then supplier 2's unit cost determines the equilibrium quality. If* $d(2c_1-c_2)-y \geq 0$*, then the conditions hold automatically.*
We define $Z_1 = \sqrt{(d\hat{\omega}+c_2\theta)^2+4y\theta\hat{\omega}}$ *and* $Z_2 = \sqrt{(d(\hat{\omega}+\hat{p})+c_2\theta)^2+4y\theta(\hat{\omega}+\hat{p})}$*.*

Lemma 3(i) defines a sufficient condition such that competition has no effect on the incumbent supplier's quality proposal and equilibrium quality level. Instead, the equilibrium quality is determined by the supplier's profit-maximizing quality when he does not have to compete with the second supplier. For these cases, the buyer's and the incumbent supplier's decisions match their decisions under the single-supplier model (§4.1). Analytically we can show that the condition in Lemma 3(i) holds only when the second supplier is not competitive on cost (i.e., c_2 is high relative to c_1) and under Case 2 (i.e., $\frac{d}{\theta} \geq \frac{c_1}{\hat{\omega}}$), which occurs when the relative market awareness of quality is high and/or the supplier's existing margin is high. We emphasize that Case 2 is not sufficient to ensure that the condition holds.

Conversely, Lemma 3(ii) defines sufficient conditions such that competition drives the supplier's quality performance. That is, the incumbent supplier's best-response quality level from the competition stage is determined by the extent to which supplier 2 can propose a quality investment and still maintain a profit greater than zero. The conditions defined in Lemma 3(ii) hold when the second supplier is competitive on costs (i.e., c_2 is comparable to c_1) and/or the supplier does not face a significant investment cost to build quality (i.e., y is low).

When we examine the buyer's premium and cost-sharing strategy under Lemma 3(ii), we find that while the buyer may offer a premium, he does not offer to share costs with his incumbent supplier.

PROPOSITION 2. *Under supplier competition and Lemma 3(ii), the buyer never shares the supplier's investment cost (i.e.,* $\gamma_C^* = 0$*) and he offers the supplier a premium if* $\hat{p} - \hat{\omega} \geq \frac{2\theta\hat{\omega}(c_2 d+2y)+c_2^2\theta^2}{d^2(\hat{p}+\hat{\omega})}$*. Furthermore, if the buyer offers the supplier a premium, then the premium is decreasing in the supplier's existing margin,* $\hat{\omega}$*, with the resulting quality level independent of* $\hat{\omega}$*.*

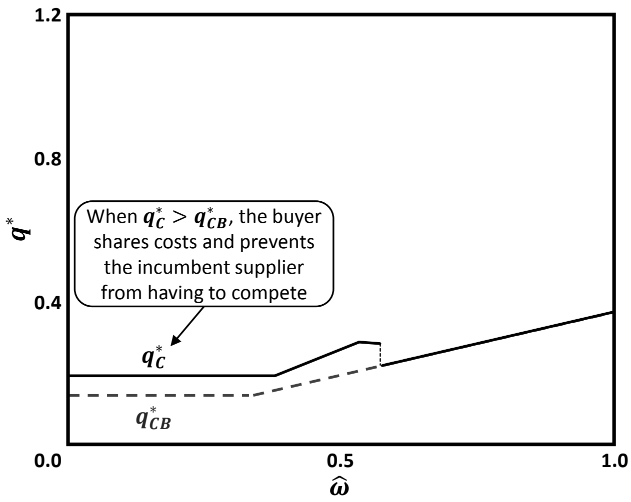
Although the incumbent supplier does not require a premium to invest in quality under supplier competition, the buyer may still offer her a premium to encourage further investment when his margin is sufficiently larger than the supplier's and consumers' environmental quality awareness, d, is high (i.e., $\hat{p}-\hat{\omega} \geq \frac{2\theta\hat{\omega}(c_2 d+2y)+c_2^2\theta^2}{d^2(\hat{p}+\hat{\omega})}$). Similar to the single-supplier model, when the buyer offers the supplier a premium, q_C^* remains constant in her existing margin, $\hat{\omega}$, while the size of the buyer's premium is decreasing in $\hat{\omega}$. See Table A.4 for the closed-form solution of the buyer's premium. Also, when Lemma 3(ii) holds, q_C^*, is nondecreasing in both $\hat{\omega}$ and consumers' environmental-quality awareness, d (see Lemma A.4 in Appendix B). While the buyer may offer $\overline{\omega}_C^* > 0$, he never offers to share costs with his incumbent supplier. Although a positive γ would help him reduce his premium offer, the savings would not be enough to offset his cost-sharing investment cost.

When neither Lemma 3(i) nor Lemma 3(ii) holds, characterizing whether $\bar{q}_2$ or q_1^* is greater is difficult. Cases can occur in which the buyer's premium and cost-sharing offers result in $q_1^* > \bar{q}_2$. Therefore, we rely on numerical analysis for the remainder of this subsection; see Table A.6 in Appendix C.1 for a summary of the complete results. We focus our discussion on the more interesting case of when the buyer utilizes cost sharing to his benefit. For comparison purposes, we include in our analysis the equilibrium quality level and premium for a base-case competition (i.e., q_{CB}^* and $\overline{\omega}_{CB}^*$) in which the buyer does not consider cost sharing as a lever to improve quality.

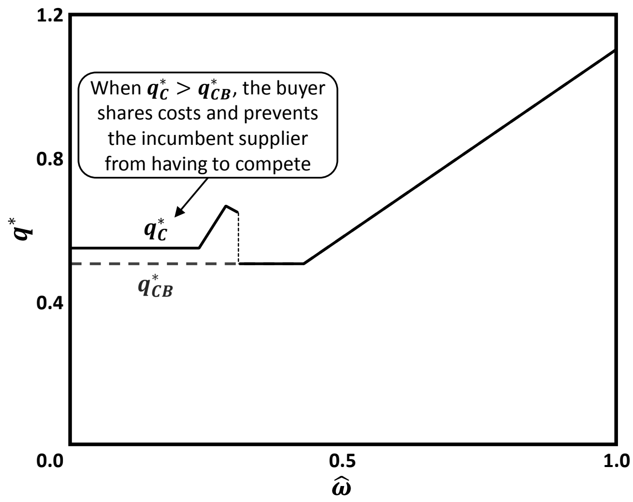
Relying on competition to drive the incumbent supplier's performance is often, but not always, the buyer's preferred strategy. When the second supplier is not competitive on cost (i.e., c_2 is high relative to c_1), demand is primarily driven by quality (i.e., d is high and θ is low), and the supplier's existing margin is low (i.e., $\hat{\omega}$ is low), the buyer's profit-maximizing strategy can be to share costs with the incumbent supplier. For these cases, the buyer shares costs and prevents the incumbent supplier from having to compete. Specifically, when cost sharing is not an option (i.e., the base-case competition), the equilibrium quality level is determined by the competitive pressure from supplier 2; i.e., $q_{CB}^* = \bar{q}_2$. However, when cost sharing is an option, the equilibrium quality level is determined by the supplier's profit-maximizing quality when he does not have to compete with the second supplier; i.e., $q_C^* = q_1^*$. Figure 2 illustrates q_C^*, $\overline{\omega}_C^*$, and γ_C^* (along with q_{CB}^* and $\overline{\omega}_{CB}^*$) for two example cases. Graphically, in Figure 2 $q_C^* = q_1^*$ when $q_C^* > q_{CB}^*$.

Figure 2 demonstrates two examples in which the buyer uses cost sharing to shield the supplier from the competition.[10] As previously stated, these cases occur when the presence of competition is not strong, and thus, in order to generate any demand, the buyer must share a low-margin incumbent supplier's cost to build quality. Similar to our single-supplier findings, cases can occur in which the buyer uses cost sharing as either a complement or a substitute for the premium. Also, how the buyer chooses to use the two levers in combination with one another is driven by the comparative difference between the supplier's unit cost impact of quality, $\frac{c}{\hat{\omega}}$, and the relative market awareness of quality, $\frac{d}{\theta}$. First, when $\frac{c}{\hat{\omega}}$ is comparable to $\frac{d}{\theta}$, as shown in Figures 2(a) and 2(c) the buyer uses cost sharing

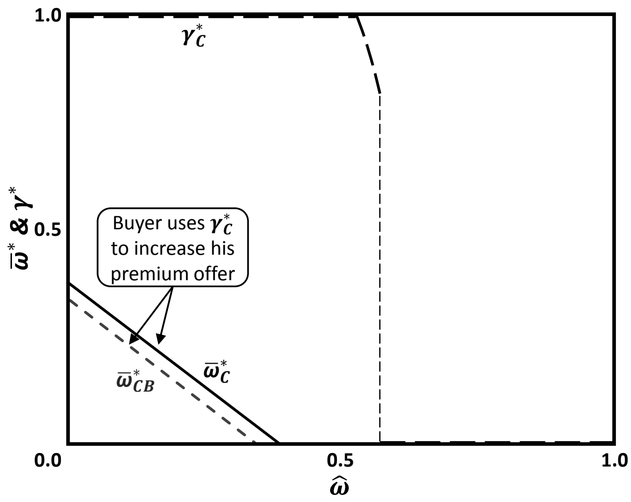
[10] Overall, cost sharing is the buyer's preferred strategy for 2.2% of all cases tested. The first (second) case discussed occurs for 0.4% (1.6%) of all cases tested.



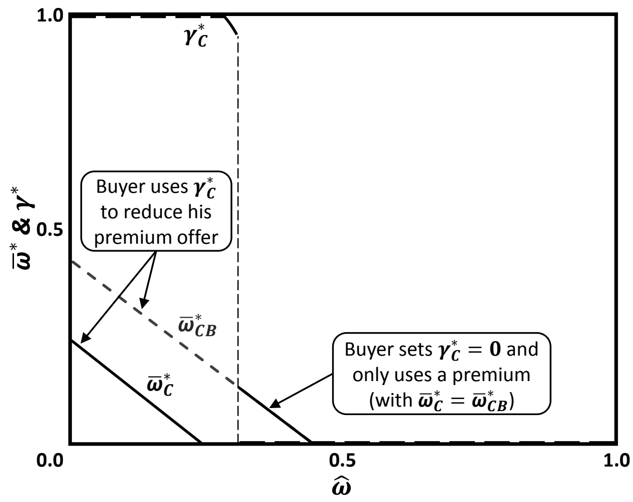
(a) q_C^* (Complements Example)



(b) q_C^* (Substitutes Example)



(c) $\overline{\omega}_C^*$ and γ_C^* as Complements



(d) $\overline{\omega}_C^*$ and γ_C^* as Substitutes

Figure 2 Supplier Competition: Environmental Quality with Respect to the Supplier's Existing Margin

Note: The following values were used to generate Figure 2, $K = 1.00$, $a = 0.90$, $d = 0.90$, $p = 1.00$, and $y = 0.40$, with $c_1 = 0.80$ and $c_2 = 2.40$ for Figures 2(a) and 2(c); $c_1 = 0.20$ and $c_2 = 0.50$ for Figures 2(b) and 2(d). Terms q_{CB}^* and $\overline{\omega}_{CB}^*$ denote the base-case equilibrium quality and premium levels for when cost sharing is not an option for the buyer.

to develop the incumbent supplier's capabilities and increase the impact of his premium offer; i.e., γ_C^* and $\overline{\omega}_C^*$ are used as complements to one another. The buyer fully subsidizes the supplier's investment cost and offers her a higher premium than he would under the base-case competition; i.e., $\gamma_C^* = 1$ and $\overline{\omega}_C^* > \overline{\omega}_{CB}^*$. By subsidizing the supplier's investment cost and increasing her margin, the buyer offsets her high unit cost and incentivizes a higher quality level than under the base case. He's also able to offer the supplier a premium for a wider range of $\hat{\omega}$ values.

Second, as shown in Figures 2(b) and 2(d), when $\frac{c}{\hat{\omega}}$ is low compared to $\frac{d}{\theta}$, the buyer fully subsidizes the incumbent supplier's investment cost but offers her a lower premium when he can share costs than when cost sharing is not an option; i.e., $\overline{\omega}_C^* < \overline{\omega}_{CB}^*$. The incumbent supplier's low unit cost reduces the need for the buyer to offer her a high premium. Because of this, the buyer's ability to share the supplier's investment cost helps him to reduce his premium offer and still incentivize a higher quality level with cost sharing.

5. GreenBlue's Strategy

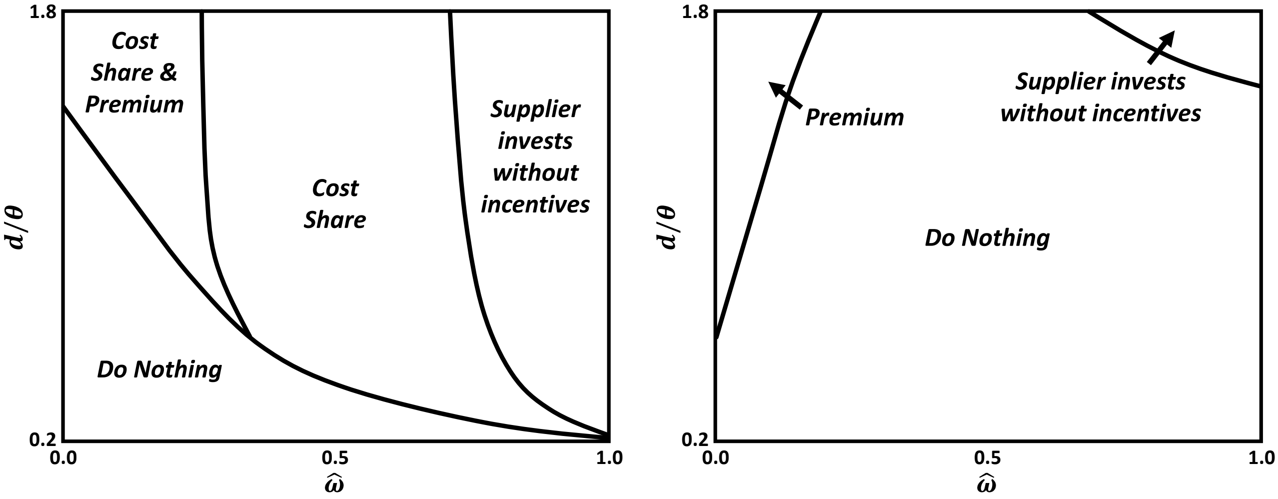
Next, based on our findings from §4, we develop insights into under what market conditions GreenBlue can promote the use of MiQ and when it can recommend that a buyer share his supplier's cost to build quality. GreenBlue is in a unique position in that as an intermediary, it can not only create a dialogue between buyers and suppliers but also act as a trusted source for transmitting sensitive environmental information. As such, MiQ has the ability to eliminate information discrepancies that may exist between a buyer and a supplier regarding the supplier's environmental performance. Nevertheless, challenges remain for GreenBlue. For example, as a nonprofit, GreenBlue cannot enforce suppliers' and buyers' use of MiQ. Instead, it can only recommend and encourage the proper usage of the tool since it maintains and administers the platform. In our analysis of GreenBlue's strategy, we focus on when opportunities exist for MiQ to improve environmental quality and do not consider GreenBlue's potential effort or costs to enforce MiQ's use.

To analyze GreenBlue's strategy, we first define its objective function. A nonprofit's objective function is often modeled as a linear combination of different goals, such as maximizing a hospital's profit and quality of care (e.g., Harrison and Lybecker 2005, Liu and Weinberg 2004, Steinberg 1986). Conversely, activists' objective functions are often modeled around a single goal, such as minimizing a manufacturer's pollution levels (e.g., Baron 2001, Baron and Diermeier 2007, Lenox and Eesley 2009). We combine these two approaches to define GreenBlue's objective function. GreenBlue is a pragmatic nonprofit that prefers to work with industry to solve environmental problems. Therefore, although GreenBlue's objective as an activist is to improve the environmental quality of products, it will only do so if buyers and suppliers do not incur decreases in profits from using MiQ.

We define GreenBlue's objective as to maximize the environmental quality invested in by the supplier in equilibrium and to identify the correct incentives (i.e., a premium and/or cost sharing) to produce that quality level. We add financial-viability constraints to ensure that both the buyer and the supplier earn profits greater than or equal to their profits under the do-nothing case; i.e., the status-quo, when both parties do not invest ($\gamma = 0$, $\overline{\omega} = 0$, and $q = 0$).[11] If for the parameter set and model tested, either the buyer or the supplier earns a profit by investing that is less than its profit for the do-nothing case, then we consider that scenario infeasible and not a valid setting for either party to implement MiQ. If instead the constraints are satisfied, then an opportunity exists for GreenBlue to promote MiQ's use. When formulating GreenBlue's optimization problem, we do not model GreenBlue's potential revenue or cost from distributing MiQ. Instead, we focus on which levers generate the highest supplier-quality level given the financial-viability constraints.

Next we present GreenBlue's preferred strategy for the single-supplier and supplier-competition models. Due to the complexity of our analysis, we present primarily numerical results.

[11] We add financial viability constraints $\pi_j^B(\gamma_j^*, \overline{\omega}_j^*, q_j^*) \geq \pi_j^B(\gamma_j = 0, \overline{\omega}_j = 0, q_j = 0)$ for the buyer, and $\Pi_j^S(\gamma_j^*, \overline{\omega}_j^*, q_j^*) \geq \Pi_j^S(\gamma_j = 0, \overline{\omega}_j = 0, q_j = 0)$ for the supplier, with $j \in \{S, C\}$.



(a) Single Supplier (b) Supplier Competition

Figure 3 GreenBlue's Strategy with Respect to $\hat{\omega}$ and $\frac{d}{\theta}$

Note: The values used to generate Figure 3 are identical to those used for Figure 1 but with d taking values from $[0.10, 0.90]$ and $c_2 = 0.50$ for Figure 3(b). Supplier invests without incentives implies that $q_i^* > 0$, $\gamma_i^* = 0$, and $\overline{\omega}_i^* = 0$ with $i \in \{S, C\}$.

Single Supplier: Figure 3(a) illustrates GreenBlue's strategy for the single-supplier model with respect to the supplier's existing margin, $\hat{\omega}$, and the relative market awareness of environmental quality, $\frac{d}{\theta}$. Comparing $\hat{\omega}$ with respect to $\frac{d}{\theta}$ demonstrates how GreenBlue's strategy changes as both the supplier's influence and consumers' sensitivity to quality change. We label when GreenBlue should recommend cost sharing, a premium, or letting the supplier invest in quality without incentives (i.e., $q_S^* > 0$, $\gamma_S^* = 0$, and $\overline{\omega}_S^* = 0$). The Do Nothing region highlights when the use of MiQ either does not produce a quality investment or does not satisfy the financial viability constraints. Otherwise, *in all other regions GreenBlue should promote the use of MiQ*. See Table A.7 in Appendix C.2 for a summary of GreenBlue's strategy for the single-supplier model.

When $\hat{\omega}$ is very high, GreenBlue's preferred strategy is to recommend that the buyer let the existing market incentives drive the supplier's quality decision and use of MiQ. Neither cost sharing nor a unit premium are effective strategies since the buyer is unwilling to invest in the supplier when her share of the supply chain margin is very high. As previously shown in Figure 1, the buyer sets $\gamma_S^* = 0$ and $\overline{\omega}_S^* = 0$, and as a result, $q_S^* = q_{SB}^*$. If instead, both the supplier's margin and the relative market awareness of quality are low, then the market elements needed to justify investment by the buyer and the supplier are not in place. Under these conditions, MiQ cannot facilitate a positive investment in environmental quality. Consequently, GreenBlue's optimal strategy is to not promote MiQ; i.e., the do-nothing case. For the remaining ranges of $\hat{\omega}$ and $\frac{d}{\theta}$ values, GreenBlue's preferred strategy is to promote the use of MiQ and encourage the buyer to share the investment cost to build quality with his existing supplier. The market opportunity along with the supplier's sufficient existing margin, present the buyer with an opportunity to share the supplier's investment cost and benefit from higher quality. For lower values of $\hat{\omega}$, as previously shown in §4.1, the buyer uses both of the levers available to him; i.e., he offers the supplier a premium while fully subsidizing her investment cost.

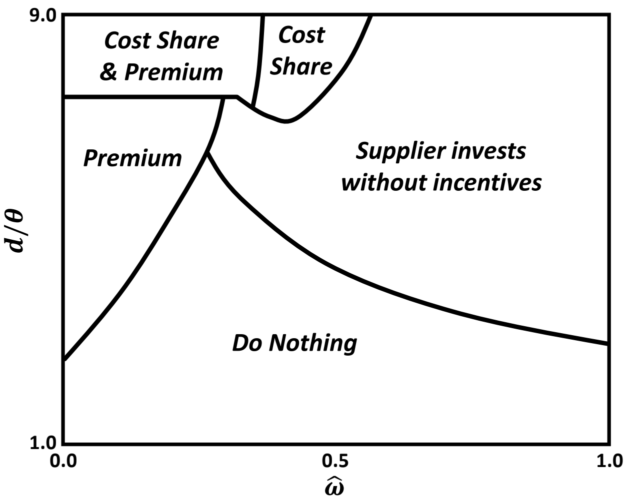
The strategies shown in Figure 3(a) are also the quality-maximizing (i.e., ignoring the financial viability constraints), and thus, buyer-profit maximizing strategies. Therefore, GreenBlue's and the buyer's strategies align under the single supplier model. As will be discussed, this is not always the case when suppliers compete.

Supplier Competition: As discussed in §4.2, when suppliers compete, cost sharing can be a viable mechanism for the buyer to use to incentivize the supplier, but only for select cases in which the second supplier is less competitive on costs, demand is primarily driven by quality, and the supplier's existing margin is low. Because of this, when GreenBlue can promote cost sharing as a viable strategy is limited and we save the presentation of these select cases until the end of the subsection. See Table A.8 in Appendix C.2 for a summary of GreenBlue's strategy under supplier competition.

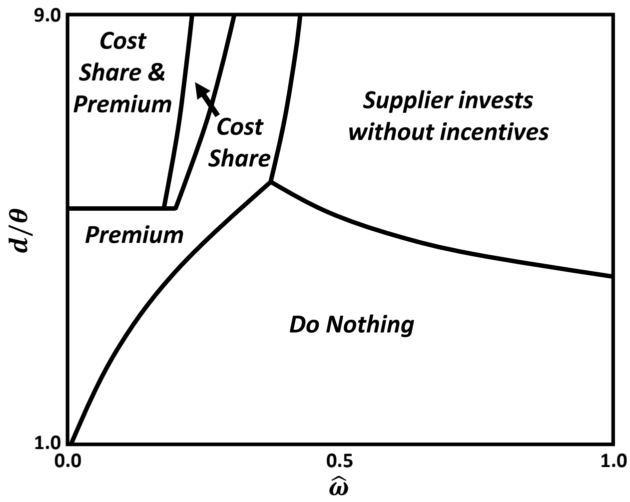
Figure 3(b) illustrates GreenBlue's strategy for the supplier-competition model. As shown, for a large number of cases, due to the presence of competition, the use of MiQ does not satisfy the financial viability constraints for the suppliers. GreenBlue's optimal strategy is not to promote the use of MiQ; i.e., the do-nothing case. Promoting MiQ is instead limited to cases in which there is a dominant player in the market and the relative market awareness of quality is high. For these cases the supplier does not suffer a loss in profit due to competition since there exists a market opportunity and GreenBlue's preferred strategy is to promote MiQ and allow competition to drive the supplier's performance. When the buyer captures most of the supply chain margin (i.e., $\hat{\omega}$ is low), he offers the supplier a premium to offset her unit cost of quality. When instead, the supplier captures most of the supply chain margin (i.e., $\hat{\omega}$ is high), the buyer does not offer her a premium. The incentives are already in place for the supplier to invest in quality on her own, without an investment from the buyer.

Figure 3(b) demonstrates how taking into consideration the financial health of buyers and suppliers can influence an activist's strategy. For the do nothing region shown in Figure 3(b), GreenBlue's and the buyer's strategies do not align. While GreenBlue's strategy in this region is to recommend that suppliers not compete on quality, the quality-maximizing (i.e., ignoring the financial viability constraints) and the buyer-profit maximizing strategies are to let the market opportunity and competition drive the supplier's quality decision (i.e., the supplier invests without incentives). Although the use of MiQ in this region is not feasible from GreenBlue's perspective, it could fit the strategy of a more purist or confrontational activist whose sole goal is to maximize environmental quality and who does not consider the impact investing in quality has on the profits of supply chain partners.

Finally, Figure 4 illustrates GreenBlue's strategy for the two cost-sharing examples discussed in §4.2 (see Figure 2). Due to the higher relative market awareness of quality, GreenBlue can promote MiQ's use for a wider range of cases than in Figure 3(b). While GreenBlue's strategy is often to recommend that the buyer let competition drive supplier performance, cases occur in which GreenBlue should instead recommend that the buyer share his incumbent supplier's cost to build quality. Specifically, we find that similar to the buyer's strategy, cost sharing is a valid recommendation by GreenBlue



(a) γ and $\overline{\omega}$ as Complements



(b) γ and $\overline{\omega}$ as Substitutes

Figure 4 Supplier-Competition: Examples of When Cost Sharing Is a Viable Strategy

Note: The values used to generate Figure 4 are identical to those used in Figure 2 but with d taking values from [0.10,0.90].

when the second supplier is not competitive on cost, demand is primarily driven by quality (i.e., d is high and θ is low), and the supplier's existing margin is low. Figure 4(a) shows GreenBlue's strategy for the case when the buyer uses cost sharing and the premium as complements for one another (see Figures 2(a) and 2(c) for an example d/θ case). That is, he uses cost sharing to increase the size of the premium he offers since the supplier's unit cost impact of quality, $\frac{c}{\hat{\omega}}$, is comparable to the relative market awareness of quality, $\frac{d}{\theta}$. Figure 4(b) illustrates GreenBlue's strategy for the case when the buyer uses cost sharing as a substitute to reduce the size of the premium he offers; i.e., $\frac{c}{\hat{\omega}}$ is lower compared to $\frac{d}{\theta}$ (see Figures 2(b) and 2(d) for an example d/θ case).[12] Note that GreenBlue's preferred strategy is also the quality-maximizing and buyer profit-maximizing strategy for all regions shown in Figure 4 except the Do Nothing region.

As consumers' awareness and concerns regarding the chemicals found in every day products continue to grow, their purchase decisions are increasingly being dictated by the environmental quality of products. For example, the presence of potentially toxic substances in children's products has become a regular topic in the mainstream media. Reports have been published on the potential risks of chemicals such as BPA in baby bottles (Parker-Pope 2008), BFRs in car seats (Peeples 2012), and formaldehyde in baby shampoo (Thomas 2014).[13] In each case, consumers' increased awareness to the chemical makeup of the product caused them to put more of an emphasis on toxicity when making their purchasing decisions. Our findings suggest that in cases such as this, when demand is highly driven by environmental quality, opportunities exist for nonprofits to promote the use of their environmental tools

[12] Numerically we find that GreenBlue's strategy is cost sharing (with or without a premium) for 2.2% of all cases tested.

[13] Extensive coverage of BPA in baby bottles led to its removal by industry leaders (Layton 2009) and eventual regulation (Tavernise 2012). Regulations have been proposed regarding the banning of BFRs in furniture and children products (Hawthorne 2015, Simmons 2015). In response to consumer pressure, Johnson & Johnson removed the formaldehyde-releasing preservative in question from its shampoo formulation.

(even in a competitive supplier market). Furthermore, environmental collaboration between buyers and suppliers is possible if the buyer is the dominant party in the supply chain.

6. Modeling Assumptions

Next, we discuss how the buyer's, the supplier's, and GreenBlue's decisions change when we relax two of our modeling assumptions: (1) the premium the buyer pays is independent of the quality the supplier delivers; and (2) the buyer's retail and wholesale prices are fixed. Our goal in this section is not necessarily to test the robustness of our results, but rather, to investigate how they might change if we were to follow more conventional approaches to the buyer-supplier relationship and not abide by the pre-existing supply chain dynamics. The key takeaways from our analysis are as follows:

- When the buyer pays a premium dependent on quality, the equilibrium quality is almost always greater than or equal to the equilibrium quality in our original model. The buyer can use the new premium structure to either reduce his cost-sharing investment or discover new opportunities to invest in a low-margin supplier.
- The buyer uses his ability to decide the retail price to strengthen his leverage over the supplier. This can have both positive and negative implications for quality, with the buyer, in some cases, using the new lever to increase his margin and, in other cases, using it to build the base market potential.
- When the buyer decides the initial wholesale price, similar to our original model, cost sharing uncovers opportunities for him to invest in a supplier that do not exist when he only considers a premium as an option for incentiving the supplier.

We summarize our analysis below; see Appendix O.3 for the complete numerical analysis, example graphs, and the supplier best-response quality for each extension.[14]

6.1. Buyer's Premium Depends on the Quality Delivered

To examine how our results change when the buyer can stipulate a more binding agreement on the quality the supplier delivers, we examine an extension in which the premium the buyer pays the supplier depends on q. That is, he pays $\overline{\omega}q$ instead of $\overline{\omega}$ as in our original model. Our sequence of events for both the single-supplier and supplier-competition models remains the same as before, with the buyer stating $\overline{\omega}$ before the supplier decides q.

Single Supplier: When the buyer pays premium $\overline{\omega}q$, the resulting q_S^* is always greater than or equal to the resulting q_S^* when he pays $\overline{\omega}$. In particular, the effectiveness of the new wholesale-price premium increases as the supplier's existing margin, $\hat{\omega}$, decreases because $\overline{\omega}q$ helps to reduce the double marginalization effect that occurs when $\hat{\omega}$ is low. The buyer offering premium $\overline{\omega}q$ has the following effect when $\hat{\omega}$ is low and (1) $\frac{d}{\theta}$ is high: the buyer reduces or eliminates his cost-sharing offer; and (2) $\frac{d}{\theta}$ is low: the buyer discovers opportunities to incentivize a low-margin supplier with a premium (but not

[14] To compare the quality levels in our original model with the extensions, we restrict our analyses of when the buyer's premium depends on quality and when the buyer decides the retail price to cases in which Lemma 3 does not hold.

cost sharing) that do not exist in our original model. As a result, the buyer's strategy is not necessarily to always subsidize the supplier's investment cost when he offers her premium $\overline{\omega}q$.

The updates to GreenBlue's strategy follow from the two buyer cases above. Specifically, GreenBlue recommends for (1) the use of MiQ without cost sharing for cases in which previously its strategy was to recommend MiQ and cost sharing and (2) the use of MiQ for cases in which previously its strategy was do nothing.

Supplier Competition: Due to the increased effectiveness of the $\overline{\omega}q$ premium, cases no longer occur in which the buyer shares costs with his incumbent supplier under competition. Also, unlike the single-supplier model, when suppliers compete, the equilibrium quality can either be greater than or less than q_C^* in our original model. The equilibrium quality is greater when $\hat{\omega}$ is low and $\frac{d}{\theta}$ is high. The buyer utilizes $\overline{\omega}q$ to effectively incentivize a low margin supplier. The small set of cases in which q_C^* is higher when the buyer pays $\overline{\omega}$ occur when $\frac{d}{\theta}$ is high, and in our original model, the buyer shares costs but does not offer a premium (i.e., $\gamma_C^* > 0$ but $\overline{\omega}_C^* = 0$). For this range of $\hat{\omega}$ values, q_C^* is increasing in $\hat{\omega}$ (see Figure 2). As a result, the buyer paying $\overline{\omega}$ produces a higher q_C^* than him paying $\overline{\omega}q$.

GreenBlue's strategy does not change significantly when suppliers compete and the buyer offers premium $\overline{\omega}q$. The two main changes are when $\hat{\omega}$ is low and (1) $\frac{d}{\theta}$ is very high: GreenBlue recommends the use of MiQ without cost sharing for cases in which previously its strategy was to recommend MiQ and cost sharing; and (2) $\frac{d}{\theta}$ is low: GreenBlue recommends the use of MiQ for cases in which previously its strategy was do nothing.

6.2. Buyer Determines the Retail Price or the Wholesale Price

We next analyze how our results change when the buyer decides (1) the retail price or (2) the initial wholesale price. We test these two scenarios separately and only consider the buyer's perspective.

Buyer Determines the Retail Price: To analyze this scenario, we modify the sequence of events in our original model as follows: before determining the portion of the supplier's investment cost that he is willing to share, the buyer solves for price premium, $\overline{p}$, with $\overline{p} \in [-p, \theta/a]$. We set the upper bound for $\overline{p}$ such that the minimum the base market potential can be is zero; i.e., $\theta - a\overline{p} \geq 0$. Having the buyer solve for $\overline{p}$ rather than the optimal price simplifies the comparison with our original model when p is fixed (the solutions to both problems however are identical). We find that in both the single-supplier and supplier-competition models, the buyer's ability to decide the retail price, and thus, strengthen his leverage over the supplier, can have both positive and negative implications for quality.

For the *single-supplier model*, two cases occur in which the buyer increases the retail price to increase quality. First, when consumers' awareness to quality, d, is very high but their sensitivity to price, a, is very low, the buyer notably increases the retail price (as compared to our original model) and relies on demand to be driven by quality. The buyer supports the supplier by also increasing the portion of the investment cost, γ, and his margin, $\overline{\omega}$, that he shares with her. Second, when the supplier's existing margin, $\hat{\omega}$, is high, the buyer sets $\overline{p}_S^* > 0$ since the supplier already captures a large portion of the supply chain margin. This pressures the supplier to increase q_S^* (as compared to our original model).

The buyer chooses to decrease his retail price (i.e., $\overline{p}_S < 0$) when consumers are highly sensitive to price; i.e., a is high. In doing so, he decreases his margin but increases the base market potential. To offset the decrease in his margin, he also reduces his premium and cost sharing offers to the supplier (as compared to our original model). The reduced incentives de-motivate the supplier to invest in quality and as a result q_S^* is lower.

The buyer's strategy for the *supplier-competition model* is similar to his strategy for the single-supplier model, with two main differences. First, the buyer's increase in price when $\hat{\omega}$ is high actually causes the supplier to decrease her quality when suppliers compete. By increasing the price and putting more of a priority on his margin than supplier quality, the buyer reduces demand, which in turn weakens the intensity of the competition and produces a lower q_C^*. Second, when the buyer decreases his price when a is high, cases can occur in which the supplier increases her quality investment when suppliers compete. For intermediate values of $\hat{\omega}$, the increase to the base market potential caused by $\overline{p}_C^* < 0$, can cause the intensity of the competition and the resulting quality investment to increase.

Buyer Determines the Wholesale Price: Finally, we test how our results change when the buyer decides the initial wholesale price, ω, rather than offer the supplier a premium, $\overline{\omega}$. The update to our sequence of events is that the buyer decides ω after he decides γ and before the supplier decides q.[15]

For the *single-supplier model*, the buyer is willing to share his margin with the supplier only when the relative market awareness of quality, $\frac{d}{\theta}$, is high and the supplier's unit-cost of quality, c, is low. For these cases, the buyer still maintains a large portion of the supply chain margin and only offers the supplier enough of a wholesale price such that she invests. Similar to our original model, when the buyer offers a positive wholesale price, he also fully subsidizes the supplier's investment cost. Furthermore, he discovers new opportunities to invest in the supplier that do not exist when cost sharing is not an option. If a market opportunity does not exist, then the buyer keeps the whole supply chain margin and does not attempt to improve quality.

For the *supplier-competition model*, our findings when the buyer solves for ω^* are similar to our findings for the original model. The use of cost sharing is again limited to cases when $\frac{d}{\theta}$ is high and the second supplier is less competitive on costs. When $\frac{d}{\theta}$ is high and both suppliers have high unit-costs of quality, the buyer uses the wholesale price and cost sharing levers in a complementary manner. That is, he offers a higher wholesale-price when he can share costs than in the base case when he cannot share costs. When $\frac{d}{\theta}$ is lower and the suppliers' unit costs are low, the buyer uses his wholesale price and cost sharing as substitutes and reduces his wholesale price (as compared to the base case).

In summary, our analysis illustrates how the buyer, in particular, benefits when we relax our modeling assumptions. While the buyer's use of a more binding premium agreement almost always benefits

[15] Note that the resulting equilibrium when the buyer decides ω corresponds with our original model analysis when $\hat{\omega} \approx 0$.

quality, his ability to set the retail or initial wholesale price, can in some cases, hurt quality. In particular, the buyer's ability to increase or decrease the retail price can shift his focus from identifying ways to increase demand through quality, to instead, concentrating more on either increasing the base market potential or his own margin.

7. Managerial Insights and Conclusion

In this paper, we examine levers available to buyers and nonprofits for influencing the environmental performance of suppliers. Our work is motivated by Material IQ (MiQ), a new decision tool developed by GreenBlue to help suppliers safely share sensitive toxicity and compliance data with their customers. As GreenBlue takes MiQ to market, it must determine under what market conditions to promote the use of MiQ and when to recommend that buyers use its implementation as an opportunity to collaborate with suppliers. We study this problem in two parts. First, we investigate when a buyer can utilize a wholesale-price premium or buyer-supplier cost sharing to improve a supplier's environmental quality. We consider both a single-supplier and a supplier-competition setting. Based on these findings, we develop insights into GreenBlue's strategy for promoting the use of MiQ. Our analysis yields valuable insights into when buyers and nonprofits can motivate improved environmental practices in supply chains absent of regulation and based solely on market forces.

The buyer's strategy: From a buyer's perspective, both a wholesale-price premium and cost sharing can be effective levers with which to improve a supplier's environmental quality. This is particularly true in a single-supplier setting when the supplier captures a small portion of the supply chain margin and a market opportunity exists for increased quality. Under these conditions, as long as the supplier's existing margin is not too low (and thus, too costly to invest in), the buyer's optimal strategy is to offer her a premium. Interestingly, when the buyer's strategy is to offer the supplier a premium, then he should also fully subsidize her investment cost to build quality. In doing so, he increases the impact of his premium offer, and in some cases, discovers opportunities to invest in a low-margin supplier that do not exist when cost sharing is not considered as a lever. The effectiveness of the two levers decreases as the supplier's portion of the supply chain margin increases. The buyer no longer offers a premium and his optimal cost-sharing strategy shifts from fully to partially to not subsidizing the supplier's investment cost.

When suppliers compete on quality, similar to the single-supplier case, the buyer should offer a wholesale-price premium when the incumbent supplier's existing margin is relatively low and a market opportunity exists for increased quality. Although cost sharing is less effective as a lever, cases can occur in which the buyer prefers to share costs. Specifically, when the second supplier is not competitive on cost, demand is primarily driven by quality, and the supplier's existing margin is low, the buyer maximizes his profit by sharing costs and preventing his incumbent supplier from having to compete.

GreenBlue's strategy: From GreenBlue's perspective, when there exists a one-to-one relationship between a buyer and a supplier, recommending the use of MiQ is a viable strategy as long as a market opportunity exists for increased quality. Furthermore, if the supplier does not capture a significant portion of the supply chain margin, then GreenBlue should recommend the buyer share the supplier's investment cost to build quality.[16] Promoting the use of MiQ is more difficult when competition exists between suppliers. This is because suppliers competing on quality often decreases their profits, which goes against GreenBlue's strategy as a pragmatic nonprofit. Under supplier competition, only when consumers' awareness of quality is high and there is a dominant party in the supply chain should GreenBlue promote the use of MiQ. In addition, GreenBlue should recommend the buyer share his incumbent supplier's investment cost to build quality only when the second supplier is not competitive on cost, demand is primarily driven by quality, and the supplier's existing margin is low.

Our model illustrates both the potential benefits and the potential risks that a nonprofit can face as it attempts to improve the environmental performance of a supply chain. As previously stated, GreenBlue originally designed MiQ to act as a marketplace, where buyers can "shop" suppliers based on their environmental performance. A marketplace design naturally fosters competition between suppliers to improve their performance. Our research suggests that for GreenBlue and other nonprofits, encouraging these types of competitive dynamics with the labels, standards, and tools they develop may negatively impact the financial health of a supply chain. An analogous situation occurred in the 1990s when stricter standards for nutrition labels were put into effect. The cost of complying with these standards pushed a number of smaller suppliers, who lacked the resources to compete, out of business (Moorman et al. 2005). In a survey of 45 buyers conducted by the authors and GreenBlue (see Appendix §O.4 for the survey results), small, private suppliers were found to follow the poorest chemical-management practices. This suggests that as small suppliers incur costs to improve their chemical-management practices, a scenario similar to the nutrition-label example may occur. These findings further support our analytical results that as a pragmatic nonprofit, GreenBlue may want to take a more careful approach with its marketplace design in trying to improve the environmental performance of suppliers.

Appendix A: Equilibrium Analysis

In this section, we provide the derivation of the buyer's and the supplier's equilibrium strategies under the single-supplier and supplier-competition settings (for exogenous γ). The single-supplier and supplier-competition equilibrium values are summarized in Tables A.2 and A.4. Due to space constraints, we only present the derivations for exogenous γ here; the analysis for the optimal γ decisions (i.e., γ^*) is available in the Online Appendix. We defer the rest of the proofs to the Online Appendix. The buyer's and the supplier's equilibrium profit functions are available from the authors upon request. Throughout this section, we use q_j^o and $q_j^*(0)$, $j \in \{S, SB, C, CB\}$, to refer to the equilibrium quality levels when the buyer offers a premium and does not offer a premium, respectively. Similarly, we use π_j^o and $\pi_j^*(0)$, $j \in \{S, SB, C, CB\}$, to refer to the buyer's profit function when he offers a premium and does not offer a premium, respectively. Additionally, we refer to $\hat{p} + \hat{\omega}$ as the (supply) chain margin and we assume this value is constant in our comparative statics discussions.

[16] We recognize that there are additional challenges to collaboration in our setting that deserve further study. For example, the sizes of the buyer and the supplier may make collaboration difficult. In a survey of 45 buyers conducted by the authors and GreenBlue (see Appendix §O.4), we found that 13 of 29 (1 of 16) companies with revenues greater (less) than \$1B are currently participating in a collaborative chemicals-management partnership.

Table A.2 Equilibrium Results: Single Supplier Model (for $\gamma = 0$ and Exogenous γ)

Case	Conditions	$\overline{\omega}^*_{SB}$	q^*_{SB}
1	$\hat{p}+\hat{\omega} \geq \frac{\theta(3cd+2y)}{d^2}$ (Con^{1A}_{SB}) and $E_{SB}{}^{\natural} \geq 0$ (Con^{1B}_{SB})	$\frac{1}{2}\left(\hat{p}-\hat{\omega}-\frac{(cd+2y)\theta}{d^2}\right)$	$\frac{d^2(\hat{p}+\hat{\omega})-\theta(3cd+2y)}{4d(cd+y)}$
	otherwise	0	0
2	$\hat{p}-\hat{\omega} \geq \frac{\theta(cd+2y)}{d^2}$ (Con^{2}_{SB})	$\frac{1}{2}\left(\hat{p}-\hat{\omega}-\frac{(cd+2y)\theta}{d^2}\right)$	$\frac{d^2(\hat{p}+\hat{\omega})-\theta(3cd+2y)}{4d(cd+y)}$
	otherwise	0	$\frac{-c\theta+d\hat{\omega}}{2(cd+y)}$
Case	**Conditions**	$\overline{\omega}^*_{S}$	q^*_{S}
1	$\hat{p}+\hat{\omega} \geq \frac{\theta(3cd+2y(1-\gamma))}{d^2}$ (Con^{1A}_{S}) and $E^1_S{}^{\dagger} \geq 0$ (Con^{1B}_{S})	$\frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}(1-\gamma)-\hat{\omega})}{d^2(2cd+y(2-\gamma))} - \frac{\theta(c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2)}{d^2(2cd+y(2-\gamma))}$	$\frac{d^2(\hat{p}+\hat{\omega})-\theta(3cd+2y(1-\gamma))}{2d(2cd+y(2-\gamma))}$
	otherwise	0	0
2	$E^2_S{}^{\ddagger} \geq 0$ (Con^{2}_{S})	$\frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}(1-\gamma)-\hat{\omega})}{d^2(2cd+y(2-\gamma))} - \frac{\theta(c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2)}{d^2(2cd+y(2-\gamma))}$	$\frac{d^2(\hat{p}+\hat{\omega})-\theta(3cd+2y(1-\gamma))}{2d(2cd+y(2-\gamma))}$
	otherwise	0	$\frac{d\hat{\omega}-c\theta}{2(cd+y(1-\gamma))}$

$\natural$ $E_{SB} = \theta^2(2y+cd)^2 - 2d^2\theta\left((2y+3cd)\hat{p}-(2y+cd)\hat{\omega}\right) + d^4(\hat{p}+\hat{\omega})^2$

$\dagger$ $E^1_S = d^4(\hat{p}+\hat{\omega})^2 - 2d^2\theta[(3cd+2y(1-\gamma))\hat{p}-(cd+2y)\hat{\omega}] + \theta^2[4cdy(1-2\gamma)+4y^2(1-\gamma)^2+c^2d^2]$

$\ddagger$ $E^2_S = cd^3(\hat{p}-\hat{\omega}) + d^2y(\hat{p}(1-\gamma)-\hat{\omega}) - \theta[c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2]$

Analysis of Single-Supplier Model (for Exogenous γ): As a benchmark, we first present the optimal quality investment in the centralized system. The objective function of the centralized problem is max_q $(\theta + dq)(\hat{p}+\hat{\omega}-cq) - yq^2$ with the optimal quality $q^*_{Cent} = \left(\frac{d(\hat{p}+\hat{\omega})-c\theta}{2(cd+y)}\right)^+$. For the analysis of the single-supplier model, we take γ as given and solve for the equilibrium $\overline{\omega}^*_S(\gamma)$ and $q^*_S(\gamma, \overline{\omega}^*_S(\gamma))$ by backward induction. We start the analysis from the last stage; i.e., the supplier's quality investment decision given $\overline{\omega}$.

Second Stage (Supplier's Problem): The supplier's problem is to maximize her profit, given $\overline{\omega}$ and γ; i.e., max_q $\Pi^S_S = (\theta+dq)[\hat{\omega}+\overline{\omega}-cq] - (1-\gamma)yq^2$. The first-order condition of this expression is $-2q(cd+(1-\gamma)y) - c\theta + d(\hat{\omega}+\overline{\omega}) = 0$, and the second-order condition is $-2(cd+(1-\gamma)y) < 0$, which guarantees that the objective function is concave in q. Thus, the supplier's best response quality given $\overline{\omega}$ is

$$q^*_S(\gamma, \overline{\omega}) = \left(\frac{-c\theta + d(\hat{\omega}+\overline{\omega})}{2(cd+(1-\gamma)y)}\right)^+. \quad (5)$$

First Stage (Buyer's Problem): Given the supplier's best response, the buyer maximizes his own profit function; $max_{\overline{\omega}}$ $(\theta + dq^*_S(\gamma,\overline{\omega}))(\hat{p}-\overline{\omega}) - \gamma y q^*_S(\gamma,\overline{\omega})^2$. Note that when $q^*_S(\gamma,\overline{\omega}) = q^o_S(\gamma,\overline{\omega}) = \frac{-c\theta+d(\hat{\omega}+\overline{\omega})}{2(cd+(1-\gamma)y)}$, the buyer's profit function is concave in $\overline{\omega}$ as shown below:

$$\pi^{Bo}_S(\gamma,\overline{\omega}) = \pi^B_S(\gamma,\overline{\omega},q^o_S(\gamma,\overline{\omega})) = (\hat{p}-\overline{\omega})\left(\theta + d\frac{-c\theta+d(\hat{\omega}+\overline{\omega})}{2(cd+(1-\gamma)y)}\right) - \gamma y\left(\frac{-c\theta+d(\hat{\omega}+\overline{\omega})}{2(cd+(1-\gamma)y)}\right)^2$$

where the FOC is $-\frac{(cd+y)(cd\theta+2y\theta+d^2(\hat{p}+\hat{\omega}+2\overline{\omega}))+y\gamma(d^2(-\hat{p}+\overline{\omega})+4\theta(cd+y))-2\theta y^2\gamma^2}{2(cd+y(1-\gamma))^2}$ and the SOC is $-\frac{d^2(2cd+y(2-\gamma))}{2(cd+y(1-\gamma))^2} < 0$. The maximizer of this function is $\overline{\omega}^o_S(\gamma) = \frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}(1-\gamma)-\hat{\omega})-\theta(c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2)}{d^2(2cd+y(2-\gamma))}$. Given this, we characterize the buyer's best response for two cases: Case 1 ($\frac{d}{\theta} < \frac{c}{\hat{\omega}}$) and Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$).

Case 1 ($\frac{d}{\theta} < \frac{c}{\hat{\omega}}$): Here, the supplier does not invest in quality unless she receives a large enough premium from the buyer. Under this case, the buyer's profit function is

$$\pi^B_S = \begin{cases} \theta(\hat{p}-\overline{\omega}) & 0 \leq \overline{\omega} < \frac{c\theta - d\hat{\omega}}{d}, \\ \pi^{Bo}_S(\gamma,\overline{\omega}) & \overline{\omega} \geq \frac{c\theta - d\hat{\omega}}{d}. \end{cases}$$

The buyer's best response and the resulting supplier investment are

$$(\overline{\omega}_S^*(\gamma), q_S^*(\gamma,\overline{\omega}_S^*(\gamma))) = \begin{cases} \left(\overline{\omega}_S^o(\gamma) = \frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}(1-\gamma)-\hat{\omega})-\theta(c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2)}{d^2(2cd+y(2-\gamma))}, q_S^o(\gamma,\overline{\omega}_S^o(\gamma)) = \frac{d^2(\hat{p}+\hat{\omega})-\theta(3cd+2y(1-\gamma))}{2d(2cd+y(2-\gamma))}\right) \\ \text{if } \ \hat{p}+\hat{\omega} \geq \frac{\theta(3cd+2y(1-\gamma))}{d^2} \ \ and \\ d^4(\hat{p}+\hat{\omega})^2 - 2d^2\theta[(3cd+2y(1-\gamma))\hat{p} - (cd+2y)\hat{\omega}] + \theta^2[4cdy(1-2\gamma)+4y^2(1-\gamma)^2+c^2d^2] \geq 0 \\ (0,0) \ \ otherwise. \end{cases} \quad (6)$$

For the first line of the equilibrium, the first condition ensures that the maximizer $\overline{\omega}_S^o(\gamma)$ is higher than the threshold $\frac{c\theta-d\hat{\omega}}{d}$, and the second condition ensures that $\pi_S^B(\gamma,\overline{\omega}_S^o, q_S^*(\gamma,\overline{\omega}_S^o)) \geq \pi_S^B(\gamma,0,0)$.

Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$): Here, the supplier is willing to invest in quality even when she is not offered a premium by the buyer. The buyer's profit function is $(\hat{p}-\overline{\omega})\left(\theta + d\frac{-c\theta+d(\hat{\omega}+\overline{\omega})}{2(cd+y(1-\gamma))}\right) - \gamma y \left(\frac{-c\theta+d(\hat{\omega}+\overline{\omega})}{2(cd+y(1-\gamma))}\right)^2$ for all $\overline{\omega} \geq 0$. Under these conditions, the equilibrium values are

$$(\overline{\omega}_S^*(\gamma), q_S^*(\gamma,\overline{\omega}_S^*(\gamma))) = \begin{cases} \left(\overline{\omega}_S^o(\gamma) = \frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}(1-\gamma)-\hat{\omega})-\theta(c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2)}{d^2(2cd+y(2-\gamma))}, q_S^o(\gamma,\overline{\omega}_S^o(\gamma)) = \frac{d^2(\hat{p}+\hat{\omega})-\theta(3cd+2y(1-\gamma))}{2d(2cd+y(2-\gamma))}\right) \\ \text{if } \ cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}(1-\gamma)-\hat{\omega}) - \theta[c^2d^2+cdy(3-4\gamma)+2y^2(1-\gamma)^2] \geq 0 \\ \left(0, \frac{-c\theta+d\hat{\omega}}{2(cd+y(1-\gamma))}\right) \ \ otherwise. \end{cases} \quad (7)$$

Note from Equations (6) and (7) that if the buyer offers the supplier a premium, the premium and the equilibrium quality values (for exogenous γ) are $\overline{\omega}_S^o(\gamma)$ and $q_S^o(\gamma,\overline{\omega}_S^o(\gamma))$ (as defined above). When we take the derivative of these expressions with respect to $\hat{\omega}$, we find

$$\frac{d\overline{\omega}_S^o(\gamma)}{d\hat{\omega}} = \frac{-cd^3-d^2y}{d^2(2cd+y(2-\gamma))}, \qquad \frac{dq_S^o(\gamma,\overline{\omega}_S^o(\gamma))}{d\hat{\omega}} = 0$$

Thus, the premium expression is decreasing in $\hat{\omega}$ whereas the equilibrium quality is independent of $\hat{\omega}$ as long as the chain margin (i.e., $\hat{p}+\hat{\omega}$) is fixed.

The single-supplier base case equilibrium (and analysis) can be found by setting $\gamma = 0$ in the expressions above. The single-supplier equilibrium values (for endogenous γ and Case 2) are available in Table A.3. Note that the results regarding Case 1 are presented in full in Proposition 1.C. We defer the detailed analysis of the single-supplier equilibrium with endogenous γ case to the Online Appendix.

Analysis of the Competition Model (for Exogenous γ): In this analysis, we take γ as exogenous and characterize the equilibrium $\overline{\omega}_C^*(\gamma)$ and $q_C^*(\gamma,\overline{\omega}_C^*(\gamma))$ here. The competition model has three stages. First, the buyer sets the portion of the investment cost that he is willing to share with the incumbent supplier if she wins. Second, the buyer declares the unit premium $\overline{\omega}$ that he is willing to pay. Third, the suppliers compete by proposing the quality levels q_i that they are willing to offer to work with the buyer. The buyer selects the supplier with the highest quality proposal and only works with her. Here, we assume that *the buyer prefers the incumbent supplier (supplier 1) whenever he is indifferent* ($q_1 = q_2$). We also assume that whenever there exist multiple equilibria in the competition stage, *supplier 1 has enough bargaining power to steer the game to the lowest-quality equilibrium*; i.e., the one she prefers the most. We find the equilibrium by backward induction; i.e., we start from the third stage (supplier-competition stage).

Third Stage (Suppliers' Competition): First, for a given pair of $(\gamma,\overline{\omega})$, the suppliers' (potential) profit functions are as follows:

$$\Pi_C^{S_1}(\gamma,\overline{\omega},q) = (\theta+dq)(\hat{\omega}+\overline{\omega}-c_1q) - (1-\gamma)yq^2,$$
$$\Pi_C^{S_2}(\overline{\omega},q) = (\theta+dq)(\hat{\omega}+\overline{\omega}-c_2q) - yq^2.$$

Table A.3 **Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$): Single-Supplier Equilibrium Strategies (for Endogenous γ)**

γ_S^*	**Premium**	Conditions
1	Yes	$d^2\hat{p} \geq E_2$
1	No	$2d\hat{p} - (d\hat{\omega} - c\theta) \geq \frac{2y}{cd}(d\hat{\omega} - c\theta)$ AND $d^2\hat{p}^2 < E_1$ or $E_1 \leq d^2\hat{p}^2$ and $d^2\hat{p} < min(4cd\theta, E_2)$ or $E_1 \leq d^2\hat{p}^2$ and $4cd\theta < d^2\hat{p} < min(E_2, 4\theta(cd+y))$ or $E_1 \leq d^2\hat{p}^2$ and $4\theta(cd+y) < d^2\hat{p} < d(d\hat{\omega} - c\theta) + 2\theta(cd+y)$ or $E_1 \leq d^2\hat{p}^2$ and $max(4cd\theta, d(d\hat{\omega} - c\theta) + 2\theta(cd+y)) < d^2\hat{p} < E_2$
$(0,1)$	No	$\frac{2y}{cd}(d\hat{\omega} - c\theta) > 2d\hat{p} - (d\hat{\omega} - c\theta) > 0$ AND $d^2\hat{p}^2 < E_1$ or $E_1 \leq d^2\hat{p}^2$ and $d^2\hat{p} < min(4cd\theta, E_2)$ or $E_1 \leq d^2\hat{p}^2$ and $4cd\theta < d^2\hat{p} < min(E_2, 4\theta(cd+y))$ or $E_1 \leq d^2\hat{p}^2$ and $4\theta(cd+y) < d^2\hat{p} < d(d\hat{\omega} - c\theta) + 2\theta(cd+y)$ or $E_1 \leq d^2\hat{p}^2$ and $max(4cd\theta, d(d\hat{\omega} - c\theta) + 2\theta(cd+y)) < d^2\hat{p} < E_2$
0	No	$2d\hat{p} - (d\hat{\omega} - c\theta) \leq 0$ AND $d^2\hat{p}^2 < E_1$ or $E_1 \leq d^2\hat{p}^2$ and $d^2\hat{p} < min(4cd\theta, E_2)$ or $E_1 \leq d^2\hat{p}^2$ and $4\theta(cd+y) < d^2\hat{p} < d(d\hat{\omega} - c\theta) + 2\theta(cd+y)$
$E_1 = (8\theta/d)(d\hat{\omega} - c\theta)(cd+y)$ $E_2 = ((d\hat{\omega} - c\theta)(cd+y)/c) + 2dc\theta$		

Note that, since $c_2 > c_1$, $\Pi_C^{S_1}(\gamma, \varpi, q) > \Pi_C^{S_2}(\varpi, q)$ for a given q, and for all $\gamma \in [0,1]$. Before stating the competition stage equilibrium, we also need to recall our assumption that the supplier that does not win the competition does not earn the buyer's business and earns zero profit.

Theorem A.1 below summarizes the equilibria for the supplier-competition stage. We define q_1^* as the incumbent supplier's profit-maximizing quality (when she does not have to compete with supplier 2); $\bar{q}_1$ and $\bar{q}_2$ as the maximum quality levels suppliers 1 and 2 can achieve without incurring profits less than zero.

Theorem A.1. *For a given pair of (γ, ϖ) declared by the buyer, (q,q) is an equilibrium of the supplier-competition stage for all $q \epsilon [max(\bar{q}_2, q_1^*), \bar{q}_1]$. In addition, $(q_1^*, [0, q_1^*])$ are equilibria when $\bar{q}_2 < q_1^*$, where we define $\bar{q}_1$, $\bar{q}_2$, and q_1^* as follows:*

$$\Pi_C^{S_1}(\gamma, \varpi, \bar{q}_1) = (\theta + d\bar{q}_1)(\hat{\omega} + \varpi - c_1\bar{q}_1) - y(1-\gamma)\bar{q}_1^2 = 0 \Rightarrow \bar{q}_1 = \frac{\sqrt{(d(\hat{\omega} + \varpi) + c_1\theta)^2 + 4y(1-\gamma)\theta(\hat{\omega} + \varpi)} + d(\hat{\omega} + \varpi) - c_1\theta}{2(c_1 d + y(1-\gamma))} \quad (8)$$

$$\Pi_C^{S_2}(\varpi, \bar{q}_2) = (\theta + d\bar{q}_2)(\hat{\omega} + \varpi - c_2\bar{q}_2) - y\bar{q}_2^2 = 0 \Rightarrow \bar{q}_2 = \frac{\sqrt{(d(\hat{\omega} + \varpi) + c_2\theta)^2 + 4y\theta(\hat{\omega} + \varpi)} + d(\hat{\omega} + \varpi) - c_2\theta}{2(c_2 d + y)} \quad (9)$$

$$q_1^* = argmax_q \ \Pi^{S_1}(\gamma, \varpi, q) \Rightarrow q_1^* = \left(\frac{d(\hat{\omega} + \varpi) - c_1\theta}{2(c_1 d + y(1-\gamma))}\right)^+. \quad (10)$$

In any of the equilibria above, supplier 1 wins the competition stage, and the minimum quality level is $max(\bar{q}_2, q_1^*)$.

Proof of Theorem A.1: Comparing Equations (8) and (10) above, $\bar{q}_1 \geq q_1^*$ since $\hat{\omega} > 0$ and $\varpi \geq 0$. Supplier 2 earns exactly zero profit if she invests $\bar{q}_2$ and works with the buyer. The supplier who loses the competition will make a profit of zero (i.e., not earn the buyer's business). Comparing Equations (8) and (9), we know that $\bar{q}_1 > \bar{q}_2$ when $\hat{\omega} > 0$ since $c_2 > c_1$. Thus, we will either have $\bar{q}_2 < q_1^* < \bar{q}_1$ or $q_1^* \leq \bar{q}_2 < \bar{q}_1$. We find the stated equilibria in the Theorem by eliminating all other cases first.

(1) *There does not exist an equilibrium where $q_i > \bar{q}_1$ is played by either player.*

(i) Suppose that supplier 1 sets $q_1 > \bar{q}_1$. Supplier 2's best response would be $q_2 \in [0, q_1]$. However, under these conditions, supplier 1 would be better off with $q_1 \in [0, q_2)$ where she would generate at least zero profit instead of incurring a loss.

(ii) Suppose now that supplier 2 sets $q_2 > \bar{q}_1$. Supplier 1's best response would be $q_1 \in [0, q_2)$. Then supplier 2 would be better off with $q_2 \in [0, q_1]$.

(2) *There does not exist an equilibrium where $q_i < max(\bar{q}_2, q_1^*)$ is played by either player, except when supplier 2 plays it and $\bar{q}_2 < q_1^*$.* We consider two subcases in this analysis: $q_1^* \le \bar{q}_2$ and $\bar{q}_2 < q_1^*$.

(i) Case 1 ($q_1^* \le \bar{q}_2$): Here we consider the cases where $q < max(\bar{q}_2, q_1^*) = \bar{q}_2$.

(a) Suppose that supplier 1 sets $q_1 < \bar{q}_2$. Then either $q_1 < q_2 \le \bar{q}_2$, $q_1 < \bar{q}_2 \le q_2$, or $q_2 \le q_1 < \bar{q}_2$ should hold. In the first case, supplier 1 would want to increase q_1 to q_2. In the second case, supplier 2 would want to decrease q_2 such that $q_1 < q_2 < \bar{q}_2$. In the third case, supplier 2 would want to increase q_2 such that $q_1 < q_2 < \bar{q}_2$. Thus, supplier 1 cannot set $q_1 < \bar{q}_2$ in equilibrium.

(b) Now suppose that we have $q_2 < \bar{q}_2$. Then we may have either $q_2 \le q_1 < \bar{q}_2$, $q_1 < q_2 < \bar{q}_2$, or $q_2 < \bar{q}_2 < q_1$. In the first case, supplier 2 would want to increase q_2. In the second case, supplier 1 would want to increase q_1. In the third case, supplier 1 would want to decrease q_1. Thus, supplier 2 cannot set $q_2 < \bar{q}_2$ in equilibrium.

(ii) Case 2 ($\bar{q}_2 < q_1^*$): Here we consider the cases where $q < max(\bar{q}_2, q_1^*) = q_1^*$.

(a) Suppose that supplier 1 sets $q_1 < q_1^*$. If $q_1 < q_2$, then supplier 1 has an incentive to increase q_1 to at least q_2. If $q_2 \le q_1$, then supplier 1 has an incentive to increase to q_1^*.

(b) Now suppose that supplier 2 sets $q_2 < q_1^*$. Here supplier 1's best response to q_2 such that $q_2 \le q_1^*$ would be q_1^*. Given that supplier 1 sets q_1^*, supplier 2's best response would be $q_2 \in [0, q_1^*]$. Then $(q_1^*, [0, q_1^*])$ constitutes an equilibrium if $\bar{q}_2 < q_1^*$. Here, supplier 1 is the winner of the competition.

(3) *There does not exist an asymmetric equilibrium such that $q_i > q_{-i}$ where both q_i and q_{-i} lie in the region $[max(\bar{q}_2, q_1^*), \bar{q}_1]$.* If $q_1 > q_2$, then supplier 1 would want to decrease her quality to q_2. If $q_1 < q_2$, then supplier 2 would want to deviate by decreasing her quality to q_1.

(4) *For any q such that $q \epsilon [max(\bar{q}_2, q_1^*), \bar{q}_1]$, (q, q) is an equilibrium.* Supplier 2's best response to q is $[0, q]$, and supplier 1's best response to q is $q_1 = q$. Thus, (q, q) is an equilibrium. Here, supplier 1 wins the competition. ■

Second Stage (Buyer's Premium Decision): Note that whenever Lemma 3(i) holds, q_1^* always dominates $\bar{q}_2$; i.e., the incumbent supplier's own incentives to invest are stronger than the competition pressure. Thus, the supplier-competition equilibrium in this case reduces to the single-supplier equilibrium.

From this point on, we will analyze the case where Lemma 3(ii) holds. Remember that Lemma 3(ii) guarantees that $\bar{q}_2$ will take higher values than q_1^* for all ϖ and γ values that the buyer may offer. Thus, in our backward induction to the buyer's premium and cost-sharing decisions, we will be taking $\bar{q}_2$ as the best response from the supplier-competition stage.

By Theorem A.1 and Lemma 3(ii), the best response the buyer should expect from the competition stage will be $\bar{q}_2 = \frac{\sqrt{(d(\hat{\omega}+\varpi)+c_2\theta)^2+4y\theta(\hat{\omega}+\varpi)}+d(\hat{\omega}+\varpi)-c_2\theta}{2(c_2d+y)}$. We first need to recall the sequence of events under the competition model: First, the buyer decides the supplier's investment cost that he is willing to share, and second he determines the unit premium he wants to offer. In the third stage, the suppliers compete. Note that the incumbent supplier is always the winner of the competition stage, and thus the buyer may support the supplier by offering both a premium and sharing the investment cost. Thus, the buyer maximizes his profit by solving $max_{\varpi \ge 0}\ (\theta + d\bar{q}_2(\varpi))(\hat{p} - \varpi) - \gamma y \bar{q}_2^2$.

$$\frac{d\pi_B(\varpi,\gamma)}{d\varpi} = -(\theta(c_2d+y) + d^2(\hat{\omega}+\varpi) + d\sqrt{E})\frac{(y+c_2d)(d\varpi+\sqrt{E}-d\hat{p}) + y\gamma(d(\hat{\omega}+\varpi)+\sqrt{E}-c_2\theta)}{2(c_2d+y)^2\sqrt{E}}. \quad (11)$$

where $E = (c_2\theta + d(\hat{\omega}+\varpi))^2 + 4y\theta(\hat{\omega}+\varpi)$. From the first derivative of the profit function with respect to ϖ, we can derive the following result.

LEMMA A.1. *Under supplier competition and Lemma 3(ii), for a given* γ*, the buyer's profit function* $\pi_C^B(\gamma,\overline{\omega})$ *is unimodal in* $\overline{\omega}$ *and is either:*

(i) Always decreasing in $\overline{\omega}$ *if* $(c_2d+y)(-d\hat{p}+\sqrt{(d\hat{\omega}+c_2\theta)^2+4y\theta\hat{\omega}})+y\gamma(d\hat{\omega}-c_2\theta+\sqrt{(d\hat{\omega}+c_2\theta)^2+4y\theta\hat{\omega}})\geq 0$*, or*

(ii) First increasing, then decreasing in $\overline{\omega}$ *otherwise.*

Proof of Lemma A.1: By Equation (11) and the fact that $E\geq 0$, and $\sqrt{E}\geq c_2\theta$, we can conclude that the behavior of the buyer's profit function is determined by the sign of the expression $(y+c_2d)(d\overline{\omega}+\sqrt{E}-d\hat{p})+y\gamma(d(\hat{\omega}+\overline{\omega})+\sqrt{E}-c_2\theta)$. We can rearrange this expression as $d\overline{\omega}(y+c_2d+y\gamma)+(y+c_2d)(\sqrt{E}-d\hat{p})+y\gamma(d\hat{\omega}+\sqrt{E}-c_2\theta)$. This expression is increasing in $\overline{\omega}$; it will either be positive for all $\overline{\omega}\geq 0$, or will start at negative values at $\overline{\omega}=0$ and then transition to positive values as $\overline{\omega}$ increases towards $\hat{p}$ (with it guaranteed to be positive at $\overline{\omega}=\hat{p}$). Thus, we can conclude this expression will always be positive if $(c_2d+y)(-d\hat{p}+\sqrt{E_C^1})+y\gamma(d\hat{\omega}-c_2\theta+\sqrt{E_C^1})>0$ already holds (i.e., at $\overline{\omega}=0$), and will be first negative then positive as $\overline{\omega}$ increases otherwise (where $E_C^1=(d\hat{\omega}+c_2\theta)^2+4y\theta\hat{\omega}$). Since the profit function first-order derivative will have the opposite sign of this expression, we can conclude the buyer's profit is decreasing in $\overline{\omega}\geq 0$ if $(c_2d+y)(-d\hat{p}+\sqrt{E_C^1})+y\gamma(d\hat{\omega}-c_2\theta+\sqrt{E_C^1})>0$, and first increasing then decreasing otherwise. This also guarantees unimodality of the profit function. ■

LEMMA A.2. *Under supplier competition and Lemma 3(ii), for a given* $\gamma\in[0,1]$*, the buyer's optimal premium strategy is as follows:*

$$\overline{\omega}_C^*(\gamma)=\begin{cases}0 & \textit{if}\ \ (c_2d+y)(-d\hat{p}+\sqrt{(d\hat{\omega}+c_2\theta)^2+4y\theta\hat{\omega}})+y\gamma(d\hat{\omega}-c_2\theta+\sqrt{(d\hat{\omega}+c_2\theta)^2+4y\theta\hat{\omega}})>0\\ \frac{(d\hat{p}-c_2\theta)((d\hat{p}+c_2\theta)(c_2d+y)+2c_2\theta y\gamma)-2\hat{\omega}(2y^2(1+\gamma)^2\theta+c_2\theta dy(3+2\gamma)+d^2(\hat{p}y\gamma+c_2^2\theta))-d^2(c_2d+y+2y\gamma)\hat{\omega}^2}{2(c_2d+y+y\gamma)(c_2d\theta+2\theta y(1+\gamma)+d^2(\hat{p}+\hat{\omega}))} & \textit{otherwise.}\end{cases}$$

Proof of Lemma A.2: This result directly follows from Lemma A.1. When the profit function is decreasing for all $\overline{\omega}\geq 0$, $\overline{\omega}_C^*(\gamma)$ is set at zero. If it is first increasing then decreasing, the optimal $\overline{\omega}_C^*(\gamma)$ is where the derivative of the profit function takes the value of zero. Since the profit function derivative is continuous in $\overline{\omega}$, we find $\overline{\omega}_C^*(\gamma)$ as $\frac{(d\hat{p}-c_2\theta)((d\hat{p}+c_2\theta)(c_2d+y)+2c_2\theta y\gamma)-2\hat{\omega}(2y^2(1+\gamma)^2\theta+c_2\theta dy(3+2\gamma)+d^2(\hat{p}y\gamma+c_2^2\theta))-d^2\hat{\omega}^2(c_2d+y+2y\gamma)}{2(c_2d+y+y\gamma)(c_2d\theta+2\theta y(1+\gamma)+d^2(\hat{p}+\hat{\omega}))}$. Note that this value falls in the interval of $[0,\hat{p}]$. ■

Table A.4 summarizes the equilibrium premium and quality levels under supplier competition and under the assumptions of Lemma 3(ii) for exogenous γ. Note that the premium condition simplifies into $d^2\hat{p}^2-(d\hat{\omega}+c_2\theta)^2-4y\theta\hat{\omega}\geq 0$ when $\gamma=0$.

Table A.4 Equilibrium Results: Supplier Competition under Lemma 3(ii) (for Exogenous γ)

Case	Conditions	$\overline{\omega}_C^*$	q_C^*
1 & 2	$(c_2d+y)(-d\hat{p}+\sqrt{E_C^{1\,\natural}})+y\gamma(d\hat{\omega}-c_2\theta+\sqrt{E_C^1})>0$	0	$\frac{d\hat{\omega}-c_2\theta+\sqrt{E_C^1}}{2(c_2d+y)}$
	otherwise	$\frac{(d\hat{p}-c_2\theta)((d\hat{p}+c_2\theta)(c_2d+y)+2c_2\theta y\gamma)}{2E_C^{2\,\dagger}}-\frac{2\hat{\omega}(2y^2(1+\gamma)^2\theta+c_2\theta dy(3+2\gamma)+d^2(\hat{p}y\gamma+c_2^2\theta))}{2E_C^2}-\frac{d^2\hat{\omega}^2(c_2d+y+2y\gamma)}{2E_C^2}$	$\frac{-c_2\theta}{2(c_2d+y)}+\frac{d(d(\hat{p}+\hat{\omega})-c_2\theta)(c_2d\theta+dy(\hat{p}+\hat{\omega})+c_2(y\theta+E_C^{3\,\ddagger}))}{4(c_2d+y)E_C^2}+\frac{c_2^3d^2\theta^2+dy(\hat{p}+\hat{\omega})(4\theta y(1+\gamma)+d^2(\hat{p}+\hat{\omega}))}{4(c_2d+y)E_C^2}+\frac{+c_2^2d\theta(y\theta+2E_C^3)+c_2(4y^2\theta^2\gamma(1+\gamma)+2d^2(\hat{p}+\hat{\omega})(3y\theta+2E_C^3))}{4(c_2d+y)E_C^2}$

♮ $E_C^1=(c_2\theta+d\hat{\omega})^2+4y\theta\hat{\omega}$; † $E_C^2=(c_2d+y+y\gamma)(c_2d\theta+2\theta y(1+\gamma)+d^2(\hat{p}+\hat{\omega}))$; ‡ $E_C^3=d^2(\hat{p}+\hat{\omega})+2y\theta\gamma$

Appendix B: Summary of Additional Theoretical Results

LEMMA A.3. $q^*_{SB} \le q^*_S \le q^*_{Cent}$.

LEMMA A.4. *When Lemma 3(ii) holds, the supplier-competition equilibrium is such that* q^*_C *is nondecreasing in* $\hat{\omega}$ *and nondecreasing in* d.

Appendix C: Numerical Analysis

Next, we present our numerical analysis for §4 and §5. We restrict our parameters to values between 0 and 1, except for c_2. We set the supply chain margin equal to 1 with $p = 1$ and $m = 0$. We test the following parameter set: $K = 1.0$, $c_1 \in \{0.20, 0.40, 0.60, 0.80, 1.00\}$, $a \in \{0.10, 0.30, 0.50, 0.70, 0.90\}$, $d \in \{0.10, 0.30, 0.50, 0.70, 0.90\}$, $y \in \{0.20, 0.40, 0.60, 0.80, 1.00\}$, and $\hat{\omega} \in [0.01, 0.99]$. Parameter $c_2 = c_1 \times \zeta$ with $\zeta \in \{1.10, 1.50, 2.00, 2.50, 3.00\}$. Subscript P denotes cases in which the buyer offers the supplier a premium. For the supplier-competition model, we remove cases in which the conditions in Lemma 3 hold.

C.1. The Buyer's Strategy

Table A.5 defines how q^*_S changes with respect to $\hat{\omega}$. Table A.6 demonstrates the buyer's equilibrium strategy when the conditions in Lemma 3 do not hold. In Table A.6, rows 3 – 7 represent cases in which the buyer prefers to share costs and prevent the incumbent supplier from having to compete. Rows 4 and 5 (6 and 7) are when the buyer uses cost sharing and the premium as complements (substitutes) for one another. For Table A.5, of the 3,565 (976 + 2,589) cases in which $\overline{\omega}^*_S > 0$ and $\gamma^*_S = 1$, for 55.0% (1,960 cases) of these $\overline{\omega}^*_{SB} > 0$ as well. For the cases in which $\overline{\omega}^*_{SB} \ge \overline{\omega}^*_S > 0$ ($\overline{\omega}^*_S > \overline{\omega}^*_{SB} > 0$), $\frac{c}{\hat{\omega}} = 6.62$ ($\frac{c}{\hat{\omega}} = 4.83$) and $\frac{d}{\theta} = 7.49$ ($\frac{d}{\theta} = 4.97$).

Table A.5 Single Supplier: How q^*_S Changes with Respect to $\hat{\omega}$

Case	Premium	q^*_S w.r.t $\hat{\omega}$	Total Cases	q^*_S	$\hat{\omega}$	γ^*
1	No	–	33,550	0.00 [0.00,0.00]	0.42 [0.02,0.99]	0.00 [0.00,0.00]
1	Yes	Constant	976	0.20 [0.04,0.75]	0.08 [0.02,0.25]	1.00 [1.00,1.00]
2	Yes	Constant	2,589	0.22 [0.02,0.75]	0.21 [0.03,0.41]	1.00 [1.00,1.00]
2	No	Increase†	5,315	0.15 [0.00,0.93]	0.51 [0.11,0.96]	1.00 [1.00,1.00]
		Decrease	10,000	0.21 [0.01,0.93]	0.60 [0.13,0.98]	0.52 [0.00,0.99]
		Increase‡	8,600	0.25 [0.00,1.15]	0.88 [0.40,0.99]	0.00 [0.00,0.00]

Note: Values shown are Avg [Min, Max]. Total number of cases tested are 61,030. Case † is when $q^*_S > q^*_{SB}$; case ‡ is when $q^*_S = q^*_{SB}$ (see Figure 1).

Table A.6 Supplier Competition: Buyer's Equilibrium Strategy

γ^*_C	$\overline{\omega}^*_{CB}$ & $\overline{\omega}^*_C$	Total Cases	% of Cases	$\hat{\omega}$	d/θ	$c_1/\hat{\omega}$	c_1	c_2
0	$\overline{\omega}^*_{CB} = \overline{\omega}^*_C = 0$	88,112	82.0%	0.58 [0.01,0.99]	2.80 [0.33,9.00]	1.09 [0.20,100.00]	0.40 [0.20,1.00]	0.91 [0.22,3.00]
0	$\overline{\omega}^*_{CB} = \overline{\omega}^*_C > 0$	16,982	15.8%	0.14 [0.01,0.46]	4.50 [0.33,9.00]	7.13 [0.43,100.00]	0.42 [0.20,1.00]	0.87 [0.22,3.00]
> 0	$\overline{\omega}^*_{CB} = \overline{\omega}^*_C = 0$	283	0.3%	0.45 [0.31,0.64]	7.85 [2.33,9.00]	1.47 [0.39,2.70]	0.65 [0.20,1.00]	1.94 [0.60,3.00]
> 0	$\overline{\omega}^*_C > \overline{\omega}^*_{CB} > 0$	366	0.3%	0.17 [0.01,0.39]	8.48 [7.00,9.00]	9.37 [1.54,100.00]	0.76 [0.60,1.00]	2.24 [1.50,3.00]
> 0	$\overline{\omega}^*_C > \overline{\omega}^*_{CB} = 0$	48	0.0%	0.36 [0.31,0.41]	8.42 [7.00,9.00]	2.35 [1.50,3.23]	0.84 [0.60,1.00]	2.52 [1.50,3.00]
> 0	$\overline{\omega}^*_{CB} \ge \overline{\omega}^*_C > 0$	1,347	1.3%	0.14 [0.01,0.38]	7.36 [2.33,9.00]	4.97 [0.63,80.00]	0.35 [0.20,0.80]	0.99 [0.50,2.40]
> 0	$\overline{\omega}^*_{CB} > \overline{\omega}^*_C = 0$	269	0.3%	0.29 [0.13,0.44]	7.68 [2.33,9.00]	1.03 [0.45,2.14]	0.29 [0.20,0.60]	0.84 [0.50,1.80]

Note: Values shown are Avg [Min, Max]. Total number of cases tested are 107,407. Table A.6 only considers cases in which Lemma 3 does not hold.

C.2. GreenBlue's Strategy

Tables A.7 and A.8 define GreenBlue's quality-maximizing strategy by $\hat{\omega}$ and d/θ for the single-supplier and supplier-competition models. In Table A.8, row 3 (4) highlights the cases in which the buyer uses cost sharing and the premium as complements (substitutes) for one another.

Table A.7 Single Supplier: GreenBlue's Equilibrium Strategy

Strategy	Total Cases	% of Cases	$\hat{\omega}$	d/θ	γ^*
CS & P	3,770	6.1%	0.17 [0.01,0.41]	4.90 [0.71,9.00]	1.00
CS	15,177	24.5%	0.56 [0.11,0.97]	2.66 [0.33,9.00]	0.70
No CS or P	8,730	14.1%	0.88 [0.68,0.99]	3.02 [0.33,9.00]	–
DN	34,198	55.3%	0.41 [0.01,0.99]	0.74 [0.11,5.00]	–

Note: Values shown are Avg [Min, Max]. Total number of cases tested are 61,875. The abbreviations represent Cost Sharing (CS), Premium (P), Do Nothing (DN), and Supplier invests without incentives (No CS or P).

Table A.8 Supplier Competition: GreenBlue's Equilibrium Strategy

Strategy	Total Cases	% of Cases	$\hat{\omega}$	d/θ	$c_1/\hat{\omega}$	c_1	c_2
P	9,298	8.7%	0.12 [0.01,0.46]	5.16 [0.56,9.00]	10.14 [0.43, 100.00]	0.48 [0.20, 1.00]	1.08 [0.22, 3.00]
No CS or P	14,844	13.8%	0.73 [0.27,0.99]	5.94 [0.78,9.00]	0.81 [0.20, 3.70]	0.55 [0.20, 1.00]	1.40 [0.22, 3.00]
CS & P	414	0.4%	0.19 [0.01,0.41]	8.47 [7.00,9.00]	8.56 [1.50, 100.00]	0.77 [0.60, 1.00]	2.27 [1.50, 3.00]
CS & P	1,347	1.3%	0.14 [0.01,0.38]	7.36 [2.33,9.00]	4.97 [0.63, 80.00]	0.35 [0.20, 0.80]	0.99 [0.50, 2.40]
CS	552	0.5%	0.37 [0.13,0.64]	7.77 [2.33,9.00]	1.25 [0.39, 2.70]	0.48 [0.20, 1.00]	1.40 [0.50, 3.00]
DN	80,952	75.4%	0.51 [0.01,0.99]	2.31 [0.33,9.00]	1.37 [0.20, 100.00]	0.37 [0.20, 1.00]	0.79 [0.22, 3.00]

Note: Values shown are Avg [Min, Max]. Total number of cases tested are 107,407. Table A.8 only considers cases in which Lemma 3 does not hold. The abbreviations represent Cost Sharing (CS), Premium (P), Do Nothing (DN), and Supplier invests without incentives (No CS or P).

References

Agrawal, V., D. Lee. 2015. The effect of sourcing policies on a supplier's sustainable practices. Working paper, Georgetown University, Washington, DC.

Babich, V. 2006. Vulnerable options in supply chains: Effects of supplier competition. *Naval Research Logistics* **53** 656–673.

Babich, V. 2010. Independence of capacity ordering and financial subsidies to risky suppliers. *Manufacturing & Service Operations Management* **12**(4) 583–607.

Babich, V., A.N. Burnetas, P.H. Ritchken. 2007. Competition and diversification effects in supply chains with supplier default risk. *Manufacturing & Service Operations Management* **9**(2) 123–146.

Baiman, S., P.E. Fischer, M.V. Rajan. 2000. Information, contracting, and quality costs. *Management Science* **46**(6) 776–789.

Baksi, S., P. Bose. 2007. Credence goods, efficient labelling policies, and regulatory enforcement. *Environmental & Resource Economics* **37**(2) 411–430.

Balachandran, K.R., S. Radhakrishnan. 2005. Quality implications of warranties in a supply chain. *Management Science* **51**(8) 1266–1277.

Baron, D. 2001. Private politics, corporate social responsibility, and integrated strategy. *Journal of Economics and Management Strategy* **10**(1) 7–45.

Baron, D., D. Diermeier. 2007. Strategic activism and nonmarket strategy. *Journal of Economics and Management Strategy* **16**(3) 599–634.

Baron, D.P. 2010. Morally motivated self-regulation. *American Economic Review* **100**(4) 1299–1329.

Benjaafar, S., E. Elahi, K. Donohue. 2007. Outsourcing via service competition. *Management Science* **53**(2) 241–259.

Berenguer, G., A. Righter, M. Shen. 2015. Challenges and strategies in managing nonprofit operations: An operations management perspective. Working paper, Purdue University, West Lafayette, IN.

Bernstein, Z. 2015. The market for safer chemistry is huge, and Congress should help. www.greenbiz.com (retrieved: July 27, 2015), June.

Bilbrey, J. 2015. BPA-free plastic containers may be just as hazardous. ScientificAmerican.com (retrieved: Jan. 10, 2015), Aug. 11.

Bonroy, O., C. Constantatos. 2014. On the economics of labels: How their introduction affects the functioning of markets and the welfare of all participants. *American Journal of Agricultural Economics* **97**(1) 239–259.

Bottega, L., J. de Freitas. 2009. Public, private, and nonprofit regulation for environmental quality. *Journal of Economics & Management Strategy* **18**(1) 105–123.

Cachon, G.P, F. Zhang. 2007. Obtaining fast service in a queueing system via performance-based allocation of demand. *Management Science* **53**(3) 408–420.

Calveras, A., J. Ganuza, G. Llobet. 2007. Regulation, corporate social responsibility and activism. *Journal of Economics and Management Strategy* **16**(3) 719–740.

Chao, G.H., S.M.R. Iravani, R.C. Savaskan. 2009. Quality improvement incentives and product recall cost sharing contracts. *Management Science* **55**(7) 1122–1138.

Chen, S., Q. Zhang, Y.P. Zhou. 2015. Impact of supply chain transparency on sustainability under NGO scrutiny. Working paper, University of Washington, Seattle, WA.

Chouinard, Y., J. Ellison, R. Ridgeway. 2011. The sustainable economy. *Harvard Business Review* **89**(10) 52–62.

Clancy, H. 2013. Supply chain tool for Gap, H&M, Levi's gets a makeover. GreenBiz.com (retrieved: Mar. 1, 2016), Dec. 12.

Conner, A., K. Epstein. 2007. Harnessing purity and pragmatism. *Stanford Social Innovation Review* (Fall) 61–65.

Corbett, C.J., G.A. DeCroix. 2001. Shared-savings contracts for indirect materials in supply chains: Channel profits and environmental impacts. *Management Science* **47**(7) 881–893.

Dale-Harris, L. 2014. Calls to ban toxic chemicals fall on deaf ears around the world. Newsweek.com (retrieved: Jan. 8, 2014), Oct. 30.

Deng, S., W. Elmaghraby. 2005. Supplier selection via tournaments. *Production and Operations Management* **14**(2) 252–267.

DeVericourt, F., M. Lobo. 2009. Resource and revenue management in nonprofit operations. *Operations Research* **57**(5) 1114–1128.

Dowie, M. 1996. *Losing ground*. The MIT Press, Cambridge, MA.

Ewell, J. 2014. Interview by the authors. Sustainable Materials Director, GreenBlue, Feb. 3.

Federgruen, A., N. Yang. 2009. Competition under generalized attraction models: Applications to quality competition under yield uncertainty. *Management Science* **55**(12) 2028–2043.

Fischer, C., T.P. Lyon. 2014. Competing environmental labels. *Journal of Economics & Management Strategy* **23**(3) 692–716.

Friedl, G., S.M. Wagner. 2012. Supplier development or supplier switching? *International Journal of Production Research* **50**(11) 3066–3079.

Gans, N. 2002. Customer loyalty and supplier quality competition. *Management Science* **48**(2) 207–221.

Guo, R., H. Lee, R. Swinney. 2015. Responsible sourcing in supply chains. *Management Science.* Forthcoming.

Ha, A.Y., L. Li, S.M. Ng. 2003. Price and delivery logistics competition in a supply chain. *Management Science* **49**(9) 1139–1153.

Harrison, T., K. Lybecker. 2005. The effect of the nonprofit motive on hospital competitive behavior. *Contributions to Economic Analysis & Policy* **4**(1) 1–15.

Hawthorne, M. 2015. CPSC considers ban on toxic flame retardants in household products. ChicagoTribune.com (retrieved: Mar. 30, 2016), Sept. 28.

Hendrikse, G., P. Letizia. 2016. Supply chain structure incentives for corporate social responsibility. *Production and Operations Management.* Forthcoming.

Heyes, A.G., J.W. Maxwell. 2004. Private vs. public regulation: Political economy of the international environment. *Journal of Environmental Economics and Management* **48**(2) 978–996.

Hyatt, D., A. Spicer. 2012. Walmart's sustainability journey: Defining sustainable products (A). SustainabilityCases.kenexcloud.org (retrieved: Oct. 12, 2013), Dec. 4.

Iyer, A.V., L.B. Schwarz, S.A. Zenios. 2005. A principal-agent model for product specification and production. *Management Science* **51**(1) 106–119.

Jiang, L., Y. Wang. 2010. Supplier competition in decentralized assembly systems with price-sensitive and uncertain demand. *Manufacturing & Service Operations Management* **12**(1) 93–101.

Joseph, B. 2016. Dueling labels seek to anoint products free of toxic chemicals. FairWarning.org (retrieved: Mar. 1, 2016), Feb. 25.

Kary, T. 2014. Colgate total ingredient linked to hormones, cancer spotlights fda process. Bloomberg.com (retrieved: Aug. 14, 2014), Aug. 11.

Kaya, M., Ö. Özer. 2009. Quality risk in outsourcing: Noncontractible quality and private quality cost information. *Naval Research Logistics* **56** 669–685.

Kim, B. 2000. Coordinating an innovation in supply chain management. *European Journal of Operations Research* **123**(3) 568–584.

Kim, S.H., S. Netessine. 2013. Collaborative cost reduction and component procurement under information asymmetry. *Management Science* **59**(1) 189–206.

Kraft, T., Y. Zheng, F. Erhun. 2013. The NGO's dilemma: How to influence firms to replace a potentially hazardous substance. *Manufacturing & Service Operations Management* **15**(4) 649–669.

Layton, L. 2009. No BPA for baby bottles in U.S. WashingtonPost.com (retrieved: Sept. 14, 2009), Mar. 6.

Lenox, M., C. Eesley. 2009. Private environmental activism and the selection and response of firm targets. *Journal of Economics and Management Strategy* **18**(1) 45–73.

Li, C. 2013. Sourcing for supplier effort and competition: Design of the supply base and pricing mechanism. *Management Science* **59**(6) 1389–1406.

Li, C., L.G. Debo. 2009. Strategic dynamic sourcing from competing suppliers with transferable capacity investment. *Naval Research Logistics* **56**(6) 540–562.

Lien, R.W., S.M.R. Iravani, K.R. Smilowitz. 2014. Sequential resource allocation for nonprofit operations. *Operations Research* **62**(2) 301–317.

Lim, W.S. 2001. Producer-supplier contracts with incomplete information. *Management Science* **47**(5) 709–715.

Liu, S., K.C. So, F. Zhang. 2010. Effect of supply reliability in a retail setting with joint marketing and inventory decisions. *Manufacturing & Service Operations Management* **12**(1) 19–32.

Liu, Y., C. Weinberg. 2004. Are nonprofits unfair competitors for businesses? An analytical approach. *Journal of Public Policy & Marketing* **23**(Spring) 65–79.

Mendoza, A.J., R.T. Clemen. 2013. Outsourcing sustainability: A game-theoretic approach. *Environmental Systems and Decisions* **33**(2) 224–236.

Moorman, C., R. Du, C.F. Mela. 2005. The effect of standardized information on firm survival and marketing strategies. *Marketing Science* **24**(2) 263–274.

Norman, W., C. MacDonald. 2004. Getting to the bottom of "triple bottom line". *Business Ethics Quarterly* **14**(2) 243–262.

Parker-Pope, T. 2008. A hard plastic is raising hard questions. NYTimes.com (retrieved: Mar. 30, 2016), Apr. 22.

Peeples, L. 2012. Flame retardants remain widespread in children's products. HuffingtonPost.com (retrieved: Mar. 30, 2016), Mar. 6.

Peeples, L. 2015. Major medical groups increasingly warning of toxic chemical risks to unborn babies. HuffingtonPost.com (retrieved: Mar. 29, 2016), Oct. 22.

Plambeck, E., T. Taylor. 2016. Supplier evasion of a buyers audit: Implications for motivating supplier social and environmental responsibility. *Manufacturing & Service Operations Management* **18**(2) 184–197.

Plambeck, E.L., H.L. Lee, P. Yatsko. 2012. Improving environmental peformance in your Chinese supply chain. *MIT Sloan Management Review* **53**(2) 43–52.

Pratt, T. 2015. New OpenLabel app offers product information for eco-minded consumers. TheGuardian.com, (retrieved: Mar. 3, 2015), Feb. 10.

Privett, N., F. Erhun. 2011. Efficient funding: Auditing in the nonprofit sector. *Manufacturing & Service Operations Management* **13**(4) 471–488.

Qi, A., Hyun-Soo Ahn, Amitabh Sinha. 2015. Investing in a shared supplier in a competitive market: Stochastic capacity case. *Production and Operations Management* **24**(10) 1537–1551.

Revkin, A.C. 2014. Technology as a path to product transparency. NYTimes.com, (retrieved: Mar. 3, 2015), June 27.

Reyniers, D.J., C.S. Tapiero. 1995. The delivery and control of quality in supplier-producer contracts. *Management Science* **41**(10) 1581–1589.

Savaskan, R.C., L.N. Van Wassenhove. 2004. Closed-loop supply chain models with product remanufacturing. *Management Science* **50**(2) 239–252.

Savaskan, R.C., L.N. Van Wassenhove. 2006. Reverse channel design: The case of competing retailers. *Management Science* **52**(1) 1–14.

Schwartz, M., S. Paul. 1992. Resource mobilization versus the mobilization of people: Why consensus movements cannot be instruments of change. A.D. Morris, C. McClurg, eds., *Frontiers in Social Movement Theory*. Yale University Press, New Haven, CT, 205–223.

Shreeves, R. 2014. Walmart and Target increase organic and sustainable options to meet consumer demand. MNN.com, (retrieved: Mar. 3, 2015), Apr. 11.

Simmons, A. 2015. Minnesota ban on fire retardants would be toughest in nation. StarTribune.com (retrieved: Mar. 30, 2016), May. 12.

Speth, G. 2008. Environmental failure: A case for a new green politics. e360.yale.edu (retrieved: May 21, 2011), Oct. 20.

Steinberg, R. 1986. The revealed objective functions of nonprofit firms. *The Rand Journal of Economics* **17**(4) 508–526.

Storrs, C. 2016. Common chemicals linked to endometriosis, fibroids, and healthcare costs. CNN.com (retrieved: Mar. 29, 2016), Mar. 22.

Talluri, S., R. Narasimhan, W. Chung. 2010. Manufacturer cooperation in supplier development under risk. *European Journal of Operational Research* **207**(1) 165–173.

Tang, S.Y., H. Gurnani, D. Gupta. 2014. Managing disruptions in decentralized supply chains with endogenous supply process reliability. *Production and Operations Management* **23**(7) 1198–1211.

Tang, S.Y., P. Kouvelis. 2011. Supplier diversification strategies in the presence of yield uncertainty and buyer competition. *Manufacturing & Service Operations Management* **13**(4) 439–451.

Tavernise, S. 2012. F.D.A. makes it official: BPA can't be used in baby bottles and cups. NYTimes.com (retrieved: July 17, 2012), July 17.

Thomas, K. 2014. The 'no more tears' shampoo, now with no formaldehyde. NYTimes.com (retrieved: Mar. 30, 2016), Jan. 17.

Tsay, A., N. Agrawal. 2004. Channel conflict and coordination in the e-commerce age. *Production and Operations Management* **13**(1) 93–110.

Wang, Y., W. Gilland, B. Tomlin. 2010. Mitigating supply risk: Dual sourcing or process improvement? *Manufacturing & Service Operations Management* **12**(3) 489–510.

Wang, Y., Y. Xiao, N. Yang. 2014. Improving the reliability of a shared supplier with competition and spillovers. *European Journal of Operations Research* **236**(2) 499–510.

Youssef, A.B., R. Lahmandi-Ayed. 2008. Eco-labeling, competition, and environment: Endogenization of labelling criteria. *Environmental and Resource Economics* **41**(2) 133–154.

Zhu, K., R.Q. Zhang, F. Tsung. 2007. Pushing quality improvement along supply chains. *Management Science* **53**(3) 421–436.