Firm and Nonprofit Levers to Improve Suppliers' Environmental Performance

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Material IQ (MIQ) is a new decision-tool designed by GreenBlue to helps suppliers safely share sensitive chemical toxicity data with their customers. Due to its ability to act as a marketplace where a firm can compare suppliers' information, MIQ has the potential to introduce competition amongst suppliers to improve their environmental performance. As GreenBlue takes MIQ to market, it must determine when to promote the use of MIQ and whether to recommend firms use it as a platform to create competition amongst suppliers or to collaborate with an existing supplier. We study GreenBlue's problem in two parts. First, we investigate when a firm can use competition or cost sharing to improve a supplier's environmental performance. Based on our findings, we then develop insights into when and how GreenBlue should promote the use of MIQ. Our results demonstrate that a firm typically prefers for suppliers to compete to improve their performance since this often produces the highest environmental quality and the highest firm profit. However, from GreenBlue's perspective, recommending MIQ as a tool to create competition between suppliers is rarely feasible since competition can harm suppliers' financial health. Instead, GreenBlue's preferred strategy is for a firm either to use MIQ to collaborate with suppliers to improve quality or to rely on the existing market incentives to drive suppliers' use of MIQ.

Key words: Environmental quality, nonprofits, supplier competition, supplier development, sustainable operations management, game theory

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 their customers without divulging intellectual property secrets. Due to its ability to act as a marketplace where a firm can compare suppliers' information, MIQ has the potential to introduce competition amongst suppliers to improve their environmental performance. As GreenBlue takes MIQ to market, it must determine when to promote the use of MIQ and whether to recommend firms use it as a platform to create competition amongst suppliers or to collaborate with an existing supplier. We investigate GreenBlue's problem in two parts. First, we examine under what market and economic conditions, supplier competition or firm-supplier cost sharing can improve a supplier's environmental performance. Based on these findings, we then develop insights into GreenBlue's strategy for promoting when and how firms should use MIQ.

Firms have long used *competition* as a lever to improve the quality and price performance of suppliers (Laseter and Stasior 1998). More recently, firms have used competition to also improve suppliers' environmental performance. For example, in an effort to "green" its products and set standards in the retail industry, Walmart requested over 100,000 of its suppliers answer questions regarding their sustainability practices. Walmart warned that suppliers who chose not to participate would "probably (be) less relevant (to Walmart)" (Rosenbloom 2009). This strategy implicitly creates competition amongst suppliers to abide by Walmart's sustainability objectives. Conversely, firms are increasingly *collaborating* with suppliers to improve their environmental performance. 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).

According to James Ewell, Sustainable Materials Director at GreenBlue, MIQ was originally designed as "a marketplace, where in exchange for providing chemical composition information to manufacturers and retailers, suppliers would have an opportunity to 'market' their products in a third party verified system that protects suppliers' confidential information" (Ewell 2014). Our research examines how GreenBlue should recommend firms use MIQ. Specifically, whether firms should use MIQ as a platform to create competition amongst suppliers or as a collaborative mechanism with which to work with an existing supplier to improve environmental performance. We examine the problem from both a firm and a social good perspective. Our work adds to the emerging nonprofit operations management literature, an example of how a pragmatic nonprofit can work with industry to improve the environmental performance of supply chains. We contribute to the supplier competition (e.g., Cachon and Zhang 2007, Elahi et al. 2007, Gans 2002) and supplier development (e.g., Babich 2010, Liu et al. 2010, Wang et al. 2010) literatures a model that illustrates and compares the effectiveness of the two levers in improving a supplier's non-price performance.

We consider a supply chain in which a profit-maximizing firm (he) attempts to increase the environmental quality (quality) of the product his supplier (she) provides.[1] The market demand for the product is determined by both price and quality, with the price being fixed. That is, we assume that while consumers' demand for a product with higher quality is increasing, consumers expect the price for this product to remain the same. In our base case, the only lever available to the firm for improving quality is to offer the supplier a per-unit premium to offset her unit cost of quality. We examine two additional levers for improving a supplier's quality: (1) the firm introduces a second supplier to compete with the existing supplier on quality; and (2) the firm and the existing supplier share the investment cost to improve quality. From GreenBlue's perspective, understanding the impact that these levers can have on a supplier's environmental performance is critical since MIQ can be used to facilitate either dynamic. Our research goals are to (i) determine under what market and economic conditions a firm can utilize a per-unit premium, competition, or cost sharing to improve a supplier's environmental

[1] Although the purpose of MIQ is to improve the information shared between suppliers and firms, we generalize our problem to focus on quality. In our setting, quality can represent either information or physical attributes. We define a product with high environmental quality as having low impact on the environment or human health.

quality, and (ii) develop insights into when and how GreenBlue should promote the use of MIQ to increase environmental quality. GreenBlue and firms' strategies may not always align. GreenBlue is a pragmatic nonprofit that works with industry to solve environmental problems. While GreenBlue would like to maximize quality, it will only do so if both firms *and* suppliers do not incur losses.

From the firm's perspective, we find that cost sharing and competition can help to improve a supplier's quality but with some limitations. For example, under *cost sharing*, if the firm captures more of the supply chain margin than the supplier and a market opportunity exists, then his optimal strategy is to offer the supplier a unit premium *and* fully subsidize her investment cost in quality. By aggressively investing in the supplier, the firm develops her capabilities, and as a result, increases the effectiveness of the premium he offers. Cost sharing, however, is less effective as the supplier's margin increases - the firm's strategy is either to decrease his portion of the shared investment cost or if the supplier captures a large portion of the supply chain margin, not share costs. Conversely, under *supplier competition*, the supplier's quality level is nondecreasing in her portion of the supply chain margin and, in general, higher than her quality level under cost sharing. The key risk to competition is the potential negative impact that it can have on suppliers' margins and thus, financial health.

As a nonprofit, GreenBlue is in a unique position with MIQ in that it has an opportunity to influence the dynamic between firms and suppliers. Recommending MIQ as a platform for creating competition between suppliers is rarely feasible since competition often hurts suppliers' profits. Instead, we find that GreenBlue should focus on the more modest improvements that can occur when firms and suppliers work together in a collaborative relationship. For example, if a firm captures enough of the supply chain margin such that he is willing to share costs with the supplier, then GreenBlue should recommend the firm use MIQ as a tool for collaborating with an existing supplier to improve quality. Conversely, if the firm is unwilling to share costs with the supplier due to her high margin, then GreenBlue should recommend the firm let the existing market incentives drive the supplier's quality decision and use of MIQ. For settings in which consumers are particularly sensitive to the chemicals in their products, if the firm is willing to share costs with his existing supplier, then GreenBlue should recommend firms adopt MIQ with a combined strategy of supplier competition *and* 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 firm's strategy in §4 and GreenBlue's strategy in §5. In §6 we highlight our insights and conclude the paper.

2. Literature Review

Next, we discuss three streams of literature relevant to our model: nonprofit operations management, quality investment and competition, and levers for improving suppliers' non-price 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, Privett and Erhun 2011; see Berenguer et al. 2014, for a review). However, relatively few of these works examine or consider a nonprofit's activism towards firms (e.g., Kraft et al. 2013, Plambeck and Taylor 2015). Instead, most of the papers that theoretically examine activism can be found in either the strategy (e.g., Lenox and Eesley 2009) or political economy (e.g., Baron 2001) literatures. 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 their study of nonprofits into two broad categories: purists, who typically seek change through confrontation, and pragmatists, who instead prefer to work with firms to solve environmental problems. GreenBlue regularly collaborates with industry to find solutions to environmental problems. As noted by James Ewell, "GreenBlue has always been a non-profit that has been 'industry-facing' in its work [and that has 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 firm and the supplier do not incur a decrease in profits by using MIQ.

We add to the OM literature an example of how a pragmatic nonprofit can work with a firm to improve the environmental performance of his supply chain. Although the design of a nonprofit's supply chain has been well studied in the humanitarian logistics literature (e.g., Balcik and Beamon 2008, Ekici et al. 2014), we are unaware of any works that examine a nonprofit's ability to influence the design of a firm's supply chain.

Quality Investment and Competition: Quality investment decisions in a competitive environment have mainly focused on consumer-facing firms and their decisions (e.g., Banker et al. 1998, Karaer and Erhun 2015, Karmarkar and Pitbladdo 1997, Moorthy 1988). Here, quality is typically performance quality; i.e., a "demand-enhancing" attribute. Though we share the same quality and demand dynamics with this stream of literature, we focus on the quality decision of an upstream supplier and how it can be motivated by her downstream partner through competition.

A supplier's quality decision and her interactions with a buyer have been studied in various settings. For example Baiman et al. (2000), Chao et al. (2009), Lim (2001), Reyniers and Tapiero (1995), and Zhu et al. (2007) study conformance quality provided by the supplier and how it can be improved with various schemes; e.g., inspection/auditing by the buyer. These authors mainly assume that quality is unobservable (i.e., cannot be assessed by the buyer) unless inspected by the buyer. Kaya and Özer (2009) focus on performance quality that is observable but not contractible. The authors assess the "risk" associated with unverifiable quality and asymmetric cost information where the buyer may or may not commit on the end-product price. Due in part to 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. However, it is important to note that most of the information shared through MIQ is currently not required by law in the U.S. but instead, voluntary. As noted by James Ewell, 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). Thus, we model a setting in which quality is observable but not contractible. Note that we assume complete information in our model setup since GreenBlue developed MIQ to eliminate discrepancies in information between firms and suppliers. We acknowledge that how information asymmetry impacts the quality performance of a supplier under different firm-supplier dynamics is an interesting problem that deserves future investigation.

Levers for Improving Suppliers' Non-price Performance: Within the supply chain contracting literature a number of papers analyze how a firm can incentivize a supplier to improve her quality or process through supplier competition (e.g., Deng and Elmaghraby 2005, Li and Debo 2009), supplier development (e.g., Corbett and DeCroix 2001, Kim and Netessine 2013, Zhu et al. 2007), or a combination of the two dynamics (e.g., Li 2013, Li et al. 2013). Although inefficiencies occur in our setting due to the firm and the supplier making decentralized decisions, as a nonprofit, GreenBlue is not in a position to coordinate the supply chain. Therefore, we do not model the design of a contract but instead, focus on how the structure of the firm-supplier dynamic impacts a supplier's quality performance.

Models that examine how supplier competition can impact a supplier's non-price performance have been applied to a broad range of OM topics: 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., Elahi et al. 2007, Gans 2002). The supplier competition paper that most relates to ours is Elahi et al. (2007). Competition is used to elicit a supplier's quality, comparing the supplier's performance under multi-supplier and single supplier settings. The allocation of demand, not supplier performance, is used as the incentive with which to improve supplier quality. Outside of the contracting literature, there are relatively few papers (e.g., Babich 2010, Friedl and Wagner 2012, Liu et al. 2010, Talluri et al. 2010, Wang et al. 2010) that apply theoretical modeling to examine the impact of a firm sharing costs to develop a supplier's capabilities. The work that most relates to ours is Wang et al. (2010). The authors study a setting in which a firm can either source from multiple suppliers or exert effort to improve supplier reliability. Although the authors consider a dual-sourcing scenario, the suppliers do not directly compete in the model.

Within the supply chain literature, there is an emerging stream of work that investigates corporate social responsibility (CSR). One aspect that makes CSR a challenging topic to study is that CSR activities are often non-verifiable (Norman and MacDonald 2004), and therefore, difficult to enforce with contracts. As a result, papers have emerged that examine the impact that supply chain structure can have on a supplier's CSR performance.[2] For example, Mendoza and Clemen (2013) examine a setting

[2] See Tang and Kouvelis (2011) for a review of the emerging literature that examines supply chain design and *environmental* performance.

with two competing firms who can source from separate suppliers or a shared supplier. The authors consider cases where the firms can help to improve the supplier's sustainability performance. Guo et al. (2014) consider the sourcing decisions of a buyer choosing between responsible and risky suppliers. The authors examine how supplier concentration influences a firm's responsible sourcing decisions. While both papers examine how a firm-supplier dynamic can improve the social responsibility performance of a supply chain, neither paper considers the impact of supplier competition.

We contribute to the OM literature a model that examines and compares the effectiveness of supplier competition and cost sharing in improving a supplier's environmental performance. We consider our results from both a firm and a social good perspective.

3. The Model

Next, we review our model formulation and assumptions. We first discuss the base case and then we demonstrate how we adapt the base case for the cost-sharing and supplier quality competition dynamics. The three firm-supplier dynamics analyzed represent ways in which a firm can influence a supplier to improve her quality as well as ways in which a firm can adopt MIQ with suppliers. Note that proper regulations for managing chemical usage are still not in place in many countries, including the United States (Layton 2010, Rizzuto 2013). Therefore, we do not incorporate regulation into our model. Instead, we focus on GreenBlue's ability as an activist to influence the environmental performance of a supply chain strictly based on market forces.

The *base case* (B), analyzes a single firm, single supplier setting. The firm 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 quality product but not at a higher price (Hyatt and Spicer 2012). Therefore, we fix the price of the product, but allow demand to vary based on the supplier's quality. The base case sequence of events is as follows: (1) The profit-maximizing firm offers the supplier a premium that he is willing to pay to entice investment in environmental quality. (2) Based on the premium, the supplier sets her quality level, with the level impacting the end demand for the product. In the base case, the per-unit premium is the only lever available to the firm to incentivize the supplier to improve her quality.

The consumer demand for the product is given by

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

where K is the base market potential, a is consumers' price awareness, and d is consumers' environmental quality awareness. Price, p, is fixed with only environmental quality, q, being a decision variable for the supplier. We model the firm's demand as being linear in both price and quality. The linear demand form has been widely used to study demand functions composed of more than one element (e.g., Banker et al. 1998, Kaya and Özer 2009, Tsay and Agrawal 2000). The structure is suitable for our purposes since our goal is to capture the general demand effect of quality on the firm's and the supplier's decisions; we acknowledge that more complex models can be utilized to further depict the consumer perspective.

The firm's (F) profit function for the base case (B) is given by

$$\begin{aligned} \pi_B^F &= D[(p-\omega)-r] \\ &= (K-ap+dq)[(p-\omega)-r]. \end{aligned} \tag{2}$$

Here $p-\omega$ represents the firm's existing margin and r is the per-unit premium the firm offers the supplier in order to increase her environmental quality level.

After the firm decides on the premium, the supplier (S) sets the quality level, q, to maximize her own profit function below

$$\begin{aligned} \Pi_B^S &= D[(\omega-m)+(r-cq)]-yq^2, \\ &= (K-ap+dq)[(\omega-m)+(r-cq)]-yq^2. \end{aligned} \tag{3}$$

Here $\omega-m$ represents the supplier's existing margin, cq is the supplier's additional unit cost of quality, and yq^2 is the supplier's investment cost to build quality, q. We model the investment cost as a quadratic function. Thus, our assumption is that the effort to improve environmental quality has diminishing returns (see Savaskan and Wassenhove 2006, p. 242).

For the *cost-sharing dynamic* (CS) the firm shares the supplier's investment cost to build quality, yq^2, in order to improve her environmental quality level. Specifically, the firm's profit function is

$$\pi_{CS}^F = (K-ap+dq)[(p-\omega)-r]-(1-\gamma)yq^2,$$

with $0\leq\gamma<1$ and $1-\gamma$ representing the portion of the supplier's investment cost the firm is willing to incur. If $\gamma=1$, then the model setup for cost sharing and the base case are identical. The supplier's profit function is given by

$$\Pi_{CS}^S = (K-ap+dq)[(\omega-m)+(r-cq)]-\gamma yq^2.$$

Under cost sharing, the change to the base case sequence of events is that the firm determines the portion of the supplier's investment cost that he is willing to share, $1-\gamma$, *before* determining the per-unit premium that he is willing to pay the supplier. In §4.2, we analyze the firm's and the supplier's decisions for a given γ; in §4.3 we examine how our results change when the firm selects his profit-maximizing γ^*. The first case represents a setting in which neither party is the dominant entity in the supply chain, and thus, γ is determined through some exogenous negotiation. The second case represents a setting in which the firm is the dominant entity in the supply chain, and thus, sets the portion of the quality investment cost that he is willing to share with the supplier.[3]

[3] Competitors within an industry often source from the same suppliers. Therefore, a firm could be hesitant to develop the capabilities of a supplier if a competitor may benefit. In our model, we ignore the potential free-riding issue that could exist if a firm were to develop the capabilities of a common supplier. Incorporating this aspect, while likely insightful, would require us to add firm competition to our setup and would make the current model intractable.

For the *quality competition dynamic* (C), a second supplier is introduced to the base case. The supplier is identical to the existing supplier except that her unit cost of quality is higher than the existing supplier. To capture this difference, we define her unit cost factor as $\bar{c}$ with $\bar{c} > c$. We model the supplier quality competition similar to Jiang and Wang (2010) in that (1) we consider the suppliers' cost difference, $\bar{c} - c$, as the measure of competitive intensity, with the competition strengthening as the difference decreases and (2) the competitor is only used to incentivize the existing supplier to increase her effort. Hence, our focus is not on which supplier wins the competition, but instead, on how the threat of competition impacts the existing supplier's quality decision.[4]

Supplier 2's profit function is given by

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

The base case sequence of events change as follows under the competition dynamic. After the firm determines the premium that he is willing to offer, the two suppliers compete in a static game of complete information; i.e., they make their quality proposals simultaneously without observing the other's action. Supplier i's strategy is to set environmental quality level q_i. After the two suppliers compete, the firm then sources from the supplier with the maximum environmental quality level. Since the existing supplier has a lower cost, she always earns the firm's business. Thus, Equation (4) represents supplier 2's *potential* profit. For reference, Table 1 summarizes our notation.

Next, we analyze our problem by characterizing the subgame perfect Nash equilibrium for each dynamic. By backwards induction we solve for the supplier's equilibrium quality level, the firm's choice of premium, the firm's cost-sharing portion (only in §4.3), and the resulting profits for each dynamic; the detailed analysis is deferred to Appendix A. 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 D.

4. The Firm's Strategy

We divide our analysis of the levers available to the firm for improving the supplier's quality into three subsections. First, we analyze the firm's use of a premium and the supplier's need for a premium under the base case equilibrium. Second, we examine when opportunities exist for the firm to introduce either cost sharing (for a given γ) or supplier competition to improve the supplier's quality. Finally, we consider how our cost-sharing results change when the firm can set an optimal γ^* to maximize his profit. We focus on the quality outcomes from the firm'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. See Appendix A for the equilibrium derivations and results.

[4] Since c and $\bar{c}$ capture the difference in margin between the two suppliers, we assume that the two supplier's 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.

Table 1 Notation

Decision Variables	
r	Per-unit premium offered by the firm to the supplier to improve environmental quality; $r \geq 0$
γ	Portion of the supplier's investment cost the supplier pays when the firm shares costs; $0 \leq \gamma < 1$
q	Environmental quality level produced by the supplier; $q \geq 0$
Demand Parameters	
K	Base market potential
a	Consumers' price awareness effect on demand; $a > 0$
p	Firm's price; $p > 0$
d	Consumers' environmental quality awareness effect on demand; $d > 0$
Cost Parameters	
ω	Current unit wholesale price paid by the firm 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; $c > 0$
$\bar{c}$	Quality-driven unit cost increase to second supplier (competition setting only); $\bar{c} > c$
y	Supplier's investment cost factor to build quality q; $y > 0$
Consolidated Terms	
θ	Market demand potential minus the firm's price effect; $\theta = K - ap$ with $\theta > 0$
$\hat{p}$	Firm'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 $\hat{\omega} > 0$

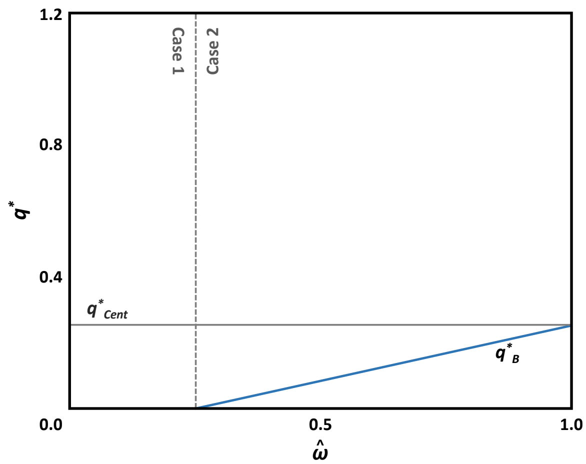
To simplify notation, we define $\theta \equiv K - ap$, $\hat{p} \equiv p - \omega$ (firm's existing margin), and $\hat{\omega} \equiv \omega - m$ (supplier's existing margin). In the appendices, we present general results for $\hat{p}$ and $\hat{\omega}$. In our numerical analysis, to demonstrate how the division of the supply chain margin between the firm and the supplier impacts our results, we fix the total supply chain margin to 1 by setting $p = 1$ and $m = 0$. Hereafter, references to the firm's or the supplier's margins are with respect to their existing margins, before a premium or quality investment is made; references to the firm's choice of premium or the supplier's choice of quality are with respect to equilibrium levels unless stated otherwise.

4.1. Unit Premium

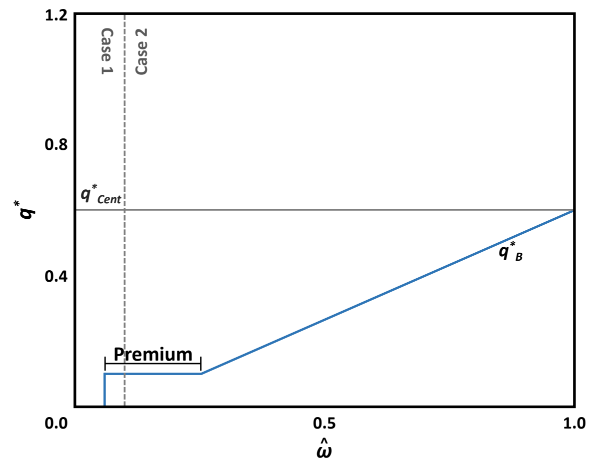
Figure 1 illustrates the supplier's equilibrium quality level for the base case, q_B^*, with respect to her margin, $\hat{\omega}$. Comparing q_B^* with respect to $\hat{\omega}$ demonstrates how quality changes as the supplier's (the firm's) portion of the supply chain margin, $\hat{\omega}$, increases ($1 - \hat{\omega}$, decreases). To show how consumer demand can influence the resulting quality level, we present q_B^* for both a low (Figure 1(a)) and a high (Figure 1(b)) consumer environmental quality awareness, d. To provide a frame of reference, we include the optimal quality level for the centralized solution, q_{Cent}^*.

The firm can offset the supplier's unit cost of quality by providing a premium. Analytically, we find that when the firm provides a premium, q_B^* remains constant in $\hat{\omega}$ while the size of r_B^* is decreasing in $\hat{\omega}$ (Proposition A.1). Graphically this implies that the firm offers the supplier a premium for any range of the supplier's margin in which $q^* > 0$ and constant in $\hat{\omega}$ (see Figure 1(b)).

The next proposition demonstrates the conditions under which the supplier requires a premium to invest in quality and the firm utilizes a premium to increase quality. We divide the proposition into



(a) $\boldsymbol{d} = 0.4$



(b) $\boldsymbol{d} = 1.0$

Figure 1 **Environmental Quality With Respect to the Supplier's Margin**

Note: The following values were used to generate Figure 1, $k = 1.00$, $a = 0.60$, $p = 1.00$, $y = 0.50$, and $c = 0.25$. The cases represent when the supplier does (Case 1) and does not (Case 2) require a premium to invest in environmental quality.

two parts. First, we consider the supplier's best response; then we analyze the firm's premium decision.

PROPOSITION 1.A. *[Supplier] Under the base case, 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.*

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., $\frac{c}{\hat{\omega}}$). As shown in Figure 1, when the supplier's portion of the supply chain margin is low (i.e., Case 1), the supplier does not invest in quality unless the firm offers her a premium to increase her margin. As the market opportunity (i.e., d) increases, however, her requirement of a premium to invest is restricted to lower values of $\hat{\omega}$. Instead, as the market opportunity outweighs the supplier's unit cost impact of quality (i.e., Case 2), the supplier can justify investment, even if the firm does not offer her a premium.

Next, we consider when the firm utilizes a premium to increase the supplier's quality under the base case. When deciding whether or not to offer the supplier a premium, the firm faces a tradeoff between a potential market opportunity and reducing his margin.[5]

PROPOSITION 1.B. *[Firm] Under the base case, the firm offers a premium to the supplier to invest in quality when either:*

(i) The supplier will not invest without a premium (Case 1), there exists an $r > 0$ *such that the firm incurs a higher profit paying a premium versus doing nothing (i.e.,* $r = 0$*,* $q = 0$*), and* $\frac{d(\hat{p}+\hat{\omega})}{\theta} \geq \frac{3cd+2y}{d}$.

(ii) The supplier will invest without a premium (Case 2) and $\frac{d(\hat{p}-\hat{\omega})}{\theta} \geq \frac{cd+2y}{d}$.

[5] We define the *do nothing case (DN)* as when both the firm and the supplier do not invest; i.e., $r = 0$ and $q = 0$.

First, consider Case 1, when the supplier does not invest in quality unless the firm offers a premium. As shown in Figure 1, although the supplier's margin is low under Case 1, this does not guarantee that the firm will offer her a premium. As $\hat{\omega}$ decreases, the size of the premium, r_B^*, that the firm must offer the supplier to incentivize her to invest in quality is increasing (Proposition A.1). Hence, when the supplier's margin is very low, there can be a misalignment of incentives as the firm may find it too costly to support the supplier when she needs it most and as shown in Figure 1, $q_B^* = 0$.

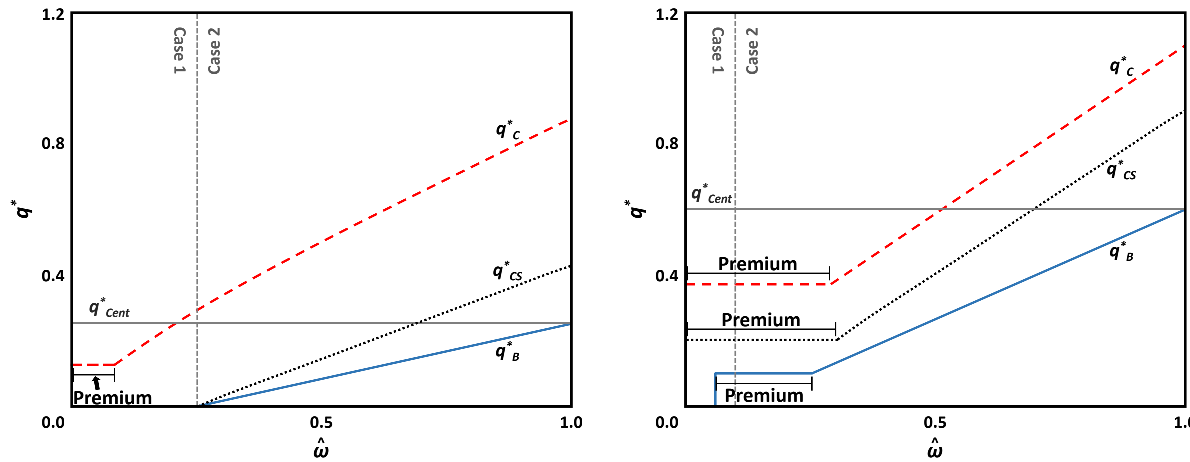
Second, consider Case 2, when the supplier invests in quality with or without a premium from the firm. For this case, the firm weighs further encouraging investment versus leaving the supplier to invest on her own. The conditions under which the firm and the supplier invest, however, are once again misaligned. The supplier's willingness to invest in quality is increasing in $\hat{\omega}$. However, as seen in Proposition 1.B(ii), while the firm may find it profitable to further encourage the supplier with a premium, his willingness to invest is limited to cases in which he captures a larger portion of the supply chain margin (i.e., $\hat{p} > \hat{\omega}$; Lemma A.2) and a market opportunity exists (i.e., d is high). Therefore, as shown in Figure 1(b), under Case 2 the firm offers the supplier a premium only when $\hat{\omega}$ is low.

4.2. Cost Sharing and Supplier Competition

Next, we incorporate cost sharing (for a given γ) and supplier competition into our analysis. Note that for extreme cases, supplier competition may not always increase quality. Specifically, if there is a large difference between the two suppliers' unit costs (i.e., $\bar{c}$ and c), then cases may occur in which competition does not influence the existing supplier's quality performance. To ensure that competition produces nontrivial results, we assume that the new supplier is competitive in terms of costs and restrict our analysis to cases in which, $d(2c - \bar{c}) + y \geq 0$ (Lemma A.1).

First, we examine when the supplier requires a premium and when the firm uses a premium to increase quality. Figure 2 adds to Figure 1 the equilibrium supplier quality for both dynamics. Although cost sharing and supplier competition introduce new incentives for the supplier to invest in quality, the firm may still find it beneficial to offer the supplier a premium under these dynamics. Similar to the base case, under cost sharing and supplier competition, when the firm offers the supplier a premium, q^* remains constant in $\hat{\omega}$ while the size of r^* is decreasing in $\hat{\omega}$ (Proposition A.1; see Figure 2).

The supplier's need for a premium is identical under the base case and cost sharing (Proposition A.2); the firm's use of a premium is very similar (Proposition A.3 and Lemma A.2). The key difference between the base case and cost sharing is the extent to which the firm is willing to utilize a premium under cost sharing. As shown in Figure 2(b), the firm is willing to offer the supplier a premium for a lower $\hat{\omega}$ under cost sharing than under the base case (Lemma A.3). This result highlights the potential benefits a firm can incur by developing his supplier's capabilities. By sharing costs, the firm reduces the supplier's investment cost, increases her ability to generate a high quality level, and thus, increases the impact of his premium investment. Cost sharing helps the firm to discover opportunities to increase



(a) $\boldsymbol{d} = 0.4$ (b) $\boldsymbol{d} = 1.0$

Figure 2 Environmental Quality With Respect to the Supplier's Margin: Supplier Competition and Cost Sharing

Note: Figure 2 adds to Figure 1 the equilibrium quality levels for supplier competition and cost sharing. The following additional values were used to generate Figure 2, $\bar{c} = 0.55$ and $\gamma = 0.50$.

demand with a low margin supplier that do not exist under the base case. This result is somewhat counterintuitive given that the firm already incurs a portion of the supplier's cost under cost sharing.

When we examine how a premium is used under supplier competition, we find that both the supplier's strategy and the firm's strategy are simplified as compared to the base case and cost sharing.

Proposition 2. *Under supplier competition: (i) The supplier always invests in quality, with or without a premium. (ii) The firm offers a premium to the supplier if* $\frac{d(\hat{p}-\hat{\omega})}{\theta} \geq \frac{2\hat{\omega}(\bar{c}d+2y)+\bar{c}^2\theta}{d}$.

When suppliers compete, the supplier does not require a premium to invest in quality. As long as a comparable second supplier is introduced (i.e., Lemma A.1 holds), the existing supplier is forced to compete and invest in quality; i.e., $q^*_C > 0$. The firm may still offer the supplier a premium to encourage further investment. However, he only does so when his margin is sufficiently larger than the supplier's (i.e., $\hat{p} > \hat{\omega}$; see Lemma A.2) and a market opportunity exists (i.e., d is high).

Next, we examine how the supplier's equilibrium quality levels under the base case, cost sharing, and supplier competition change with respect to the model parameters. As shown in Figure 2 and discussed in Proposition 3, the supplier's quality is nondecreasing in both her margin and consumers' environmental quality awareness.

Proposition 3. *The supplier's equilibrium quality levels under the base case,* q^*_B*, supplier competition,* q^*_C*, and cost sharing,* q^*_{CS}*, are such that*

(i) q^*_B, q^*_{CS}, *and* q^*_C *are nondecreasing in* $\hat{\omega}$ *and nondecreasing in* d,

(ii) $q^*_{CS} > q^*_B$ *for all* γ, $0 \leq \gamma < 1$, *and* $q^*_C > q^*_B$,

(iii) $q^*_{Cent} \geq q^*_B$,

(iv) $q^*_{CS} - q^*_{Cent}$ $(q^*_C - q^*_{Cent})$ *is increasing in* $\hat{\omega}$ *and decreasing in* γ $(\bar{c})$*; furthermore,* $q^*_{CS} > q^*_{Cent}$ $(q^*_C > q^*_{Cent})$ *is attainable.*

Proposition 3 highlights how the supplier's quality increases when either her ability to invest or her opportunity to profit improve. Take, for example, the base case. The gap between q^*_{Cent} and q^*_B (see Figure 1) represents the double marginalization effect and the resulting inefficiency that can occur when a firm and a supplier make decentralized decisions. When the firm captures the majority of the supply chain margin (i.e., $\hat{\omega}$ is low), the inefficiency is exacerbated. The firm as the downstream partner, prefers not to help a low margin supplier. The double marginalization effect begins to dissipate as the supplier's margin increases. When $\hat{\omega}$ is high, the supplier acts as if she is the single decision maker and sole entity in the supply chain. Consequently, the supplier's environmental quality level is increasing in her share of the supply chain margin for q^*_B, as well as q^*_C and q^*_{CS}. Regarding consumers' environmental quality awareness, as d increases, the greater the demand opportunity and thus, the greater the incentive for the supplier to increase her quality.

Cost sharing and supplier competition always produce a higher quality level than the base case. In the base case, the firm can only use a premium to motivate the supplier, and does not have an additional 'carrot' (i.e., cost sharing) or 'stick' (i.e., competition) to increase the supplier's quality. Under cost sharing and competition, quality levels such that $q^*_{CS} > q^*_{Cent}$ and $q^*_C > q^*_{Cent}$ are even possible when the supplier has a high margin. As $\hat{\omega}$ increases, the supplier has more flexibility to increase her unit cost to improve quality. Cost sharing reduces the size of the margin the supplier must make to recoup her investment in quality. Competition forces her to deplete her higher margin in order to produce a high q^*_C and retain the firm as a customer. Numerically, we find that $q^*_C > q^*_{Cent}$ for 75.7% of the cases tested; $q^*_{CS} > q^*_{Cent}$ for 28.7% of the cases tested.[6]

We emphasize that under all three dynamics, in equilibrium, the firm never uses a premium to induce the supplier to produce a quality level greater than the centralized solution (Lemma A.4). Either the size of the premium needed is too large or the supplier captures too much of the supply chain margin for the firm to financially justify offering a premium to achieve a quality level that high. Only when the supplier is motivated to invest on her own in quality and the firm does not find it beneficial to offer a premium, does $q^*_C > q^*_{Cent}$ or $q^*_{CS} > q^*_{Cent}$ occur.

Finally, when we compare the performance of the two dynamics, we find that the conditions under which cost sharing generates a higher quality level than competition are restricted.

LEMMA 1. *$q^*_{CS} - q^*_C$ is increasing in $\bar{c}$, and decreasing in γ and c; furthermore, $q^*_{CS} > q^*_C$ is attainable.*

Numerically we find that $q^*_C > q^*_{CS}$ for 84.9% of the cases tested (see Table A.3, Appendix D.1). Only when the firm fully or almost fully subsidizes the supplier's investment cost (i.e., γ is low) or the second supplier introduced under competition is not competitive on cost (i.e., $\bar{c}/c$ is high) does cost sharing generate a higher quality level than supplier competition.[7] Although cases can occur in which

[6] A total of 796,250 cases were tested; see Appendix D.1 for the values used. The median $\hat{\omega} = 0.80$ when $q^*_{CS} > q^*_{Cent}$ and 0.35 when $q^*_{CS} \le q^*_{Cent}$; the median $\hat{\omega} = 0.65$ when $q^*_C > q^*_{Cent}$ and 0.20 when $q^*_C \le q^*_{Cent}$.

[7] Lemma 1 follows from our results that q^*_C is nonincreasing in $\bar{c}$ and q^*_{CS} is nonincreasing in γ (Lemma A.5).

$q^*_{CS} > q^*_C$ when the supplier's margin is low, typically cost sharing generates the highest quality level only when $\hat{\omega}$ and d are high (see Figure 7 in Appendix D for a graphical example).

4.3. Firm Determines His Portion of the Shared Investment Cost

Next, we examine how our results change when the firm can set an optimal γ^* to maximize his profit. Recall that under cost sharing, the firm shares portion $1-\gamma$ of the supplier's investment cost to build quality and he determines γ before deciding on the premium that he is willing to offer the supplier.

We find that if the supplier requires a premium to invest in quality (i.e., Case 1) and the firm offers a premium, then the firm's optimal strategy is to fully subsidize the supplier's investment cost.

PROPOSITION 4. *Under cost sharing*

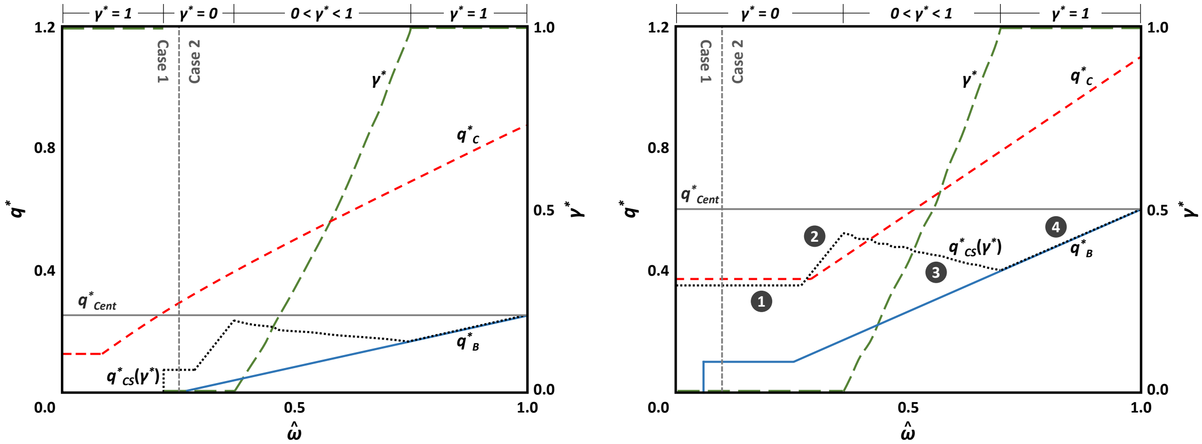
(i) If $\frac{d}{\theta} < \frac{c}{\hat{\omega}}$ (Case 1) and the firm's optimal strategy is to offer a premium, then the firm maximizes his profit by setting $\gamma^* = 0$. This strategy also produces the highest achievable quality level under cost sharing and these conditions.

(ii) If $\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$ (Case 2) and the firm's optimal strategy is to offer a premium, then his profit is decreasing in γ.

(iii) If $\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$ (Case 2) and the firm's optimal strategy is not to offer a premium, then his profit is unimodal in γ. The firm may maximize his profit by offering the supplier full, partial, or no subsidy for her investment cost.

Figure 3 replaces q^*_{CS} in Figure 2 with the firm's choice of γ^* and the resulting cost-sharing equilibrium quality level, $q^*_{CS}(\gamma^*)$. First, consider Case 1 and Figure 3(a). Consistent with our previous findings, when $\hat{\omega}$ and d are very low, the size of the premium the firm must offer the supplier to incentivize her to invest in quality is very high. Therefore, he does not offer a premium and similarly, he does not subsidize the supplier's investment cost; i.e., $\gamma^* = 1$. As a result, the supplier does not invest in quality. For higher values of either $\hat{\omega}$ or d (under Case 1), if the firm is willing to offer the supplier a premium, then the firm's optimal strategy is to fully subsidize the supplier's investment cost with $\gamma^* = 0$ (Proposition 4(i)). By fully assuming the supplier's investment cost, the firm increases the effectiveness of his premium investment in the supplier and thus, the supplier's quality level.

The firm's optimal cost-sharing investment is less straightforward under Case 2. The firm's equilibrium premium strategy depends on the cost-sharing investment cost, γ (Lemma A.6). In addition, the firm's profit is decreasing in γ when he offers a premium (Proposition 4(ii)) but is unimodal in γ when he does not offer a premium (Proposition 4(iii)). Therefore, under Case 2, the firm's optimal cost-sharing investment may be to fully (i.e., $\gamma^* = 0$), partially (i.e., $0 < \gamma^* < 1$), or not (i.e., $\gamma^* = 1$) subsidize the supplier's quality investment, potentially coupled with a premium or no premium offered to the supplier. Consider four possible ranges of $\hat{\omega}$ values for Case 2 labeled in Figure 3(b). (1) For low $\hat{\omega}$ values, the firm continues to fully subsidize the supplier's investment cost and to offer her a premium. (2) As the supplier's margin increases, however, the firm no longer offers her a premium.



(a) $\boldsymbol{d} = 0.4$ (b) $\boldsymbol{d} = 1.0$

Figure 3 **Environmental Quality With Respect to the Supplier's Margin: The Firm Selects an Optimal** γ^*

Note: Figure 3 replaces q^*_{CS} in Figure 2 with the firm's choice of γ^* and the resulting equilibrium quality level, $q^*_{CS}(\gamma^*)$.

Still, the supplier's higher margin (relative to the previous case) along with $\gamma^* = 0$ ensure that $q^*_{CS}(\gamma^*)$ is nondecreasing in $\hat{\omega}$ (similar to our findings for the given γ case in §4.2). (3) For higher values of $\hat{\omega}$, the supplier's margin is too large and for a range of the supplier's margin, γ^* is increasing in $\hat{\omega}$ and as a result, $q^*_{CS}(\gamma^*)$ 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 firm does not subsidize her investment cost as $\gamma^* = 1$ and $q^*_{CS}(\gamma^*) = q^*_B$. See Table A.4 in Appendix D.1 for the complete numerical analysis.

When the firm determines his portion of the shared investment cost, the quality level under cost sharing is rarely greater than the centralized solution as the firm sets γ^* and the premium to maximize his profit, not necessarily quality.[8] Furthermore, we find that when the firm sets γ^* and $\hat{\omega}$ is high, since $q^*_{CS}(\gamma^*)$ is either nonincreasing in $\hat{\omega}$ or equal to q^*_B, cost sharing no longer produces a higher quality level than competition. Only when $\hat{\omega}$ is low and $q^*_{CS}(\gamma^*)$ is increasing in $\hat{\omega}$ do we find select cases in which $q^*_{CS}(\gamma^*) > q^*_C$ (see Figure 3(b)).[9]

Our focus in §4 has been on environmental quality. However, to formulate GreenBlue's strategy in §5, we also need to consider the firm's and the supplier's profits for each dynamic. Figure 4 illustrates the median firm profit, supplier profit, and environmental quality across all cases tested. As shown, the firm benefits the most when suppliers compete since competition produces the highest quality and thus, firm profit. However, since competition forces the existing supplier to reduce her margin to generate a high quality, it also produces the lowest supplier profit. This suggests that while recommending MIQ as a tool to create competition between suppliers may help to improve quality, this often may not be a feasible strategy for GreenBlue who is also concerned with firms' and suppliers' financial health.

[8] For 0.1% of the 868,660 cases tested, $q^*_{CS}(\gamma^*) > q^*_{Cent}$. Unlike the given γ case, $q^*_{CS}(\gamma^*) > q^*_{Cent}$ when $\hat{\omega}$ is low and $q^*_{CS}(\gamma^*)$ is increasing in $\hat{\omega}$. For these cases the supplier's investment cost, y, is high but her unit-cost of quality, c, is low.

[9] For 8.0% of the 868,660 cases tested, $q^*_{CS}(\gamma^*) > q^*_C$. For these cases, the median $\hat{\omega} = 0.21$, competition is less effective (i.e., $\bar{c}/c$ is high), and a market opportunity exists (i.e., d/θ is high).

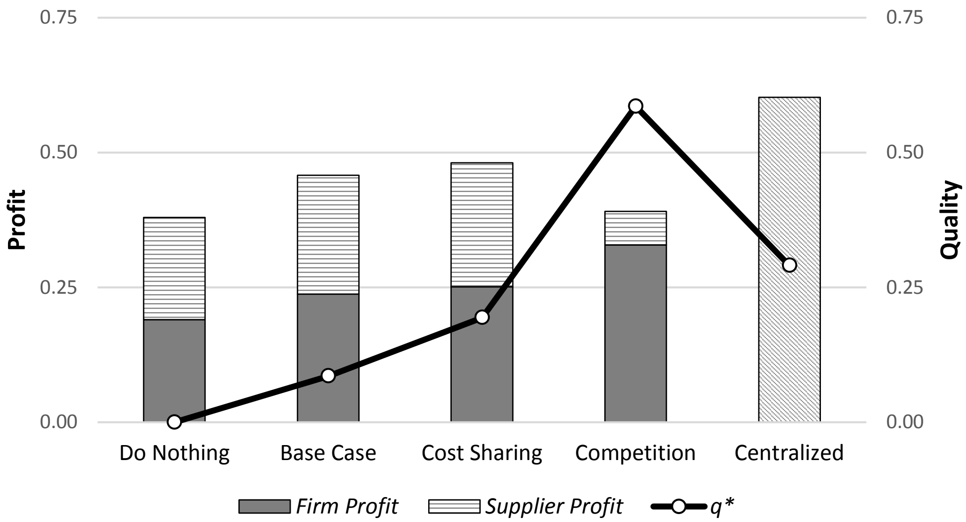


Figure 4 **Median Firm Profit, Supplier Profit, and Environmental Quality**

Note: For each dynamic, the median values of 868,660 cases tested are presented. The results shown are for the case in which the firm solves for γ^*.

5. GreenBlue's Strategy

Next, based on our findings from §4, we develop insights into when and how GreenBlue should promote the use of MIQ. A large portion of GreenBlue's potential customers are large firms with extensive market power. Therefore, we focus on the case in which the firm solves for γ^*. Due to the complexity of our analysis, we present primarily numerical results.

We first define GreenBlue's objective function. Defining a nonprofit's objective function can be difficult since nonprofits often have multiple goals (Steinberg 1986, Weisbrod 1998). Within the nonprofit literature, a nonprofit's objective function is often modeled as a linear combination of different goals (e.g., Harrison and Lybecker 2005, Liu et al. 2010, Steinberg 1986). For example, Harrison and Lybecker (2005) model a nonprofit hospital's objective function as a linear combination of the hospital's profit and quality of care. Conversely, within the political economy and strategy literatures, activists' objective functions are often modeled around a single goal (e.g., Baron 2001, Baron and Diermeier 2007, Lenox and Eesley 2009). For example, Baron (2001) model an activist's objective function to minimize a firm's pollution levels. We combine these approaches to define GreenBlue's objective function. GreenBlue is a pragmatic nonprofit that prefers to work with firms 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 the firm and the supplier do not incur losses in profits.

We define GreenBlue's objective function as the maximum quality level between the base case, cost sharing, and competition. We add constraints to our model to ensure that both the firm and the supplier earn profits greater than or equal to their profits under the do nothing case. If under the parameter set tested, either the firm or the supplier earns a profit for a firm-supplier dynamic less than its profit for the do nothing case, then we consider that dynamic infeasible and not a valid method for using MIQ. If instead, the constraints hold and quality is maximized, then an opportunity exists for GreenBlue to promote the firm's use of MIQ with the quality-maximizing dynamic.

We define GreenBlue's optimization problem as follows.[10]

$$\begin{aligned} \max_{D\in\{B,C,CS\}} \quad & z_D \\ \text{s.t. } \pi_D^F(r_D^*, q_D^*) &\geq \pi_B^F(r=0, q=0)x_D \\ \Pi_D^S(r_D^*, q_D^*) &\geq \Pi_B^S(r=0, q=0)x_D \\ q_D^* x_D &\geq z_D \\ x_D \in \{0,1\} \ & \& \ z_D \geq 0 \end{aligned}$$

Figure 5 illustrates GreenBlue's quality-maximizing strategy when we compare the performance of each dynamic with respect to the supplier's margin, $\hat{\omega}$, and the relative market awareness of environmental quality, d/θ. Comparing $\hat{\omega}$ with respect to d/θ helps us to show how GreenBlue's strategy changes as both the supplier's influence and consumers' sensitivity to quality change. To present a complete picture, we delineate when the firm does or does not offer the supplier a premium.

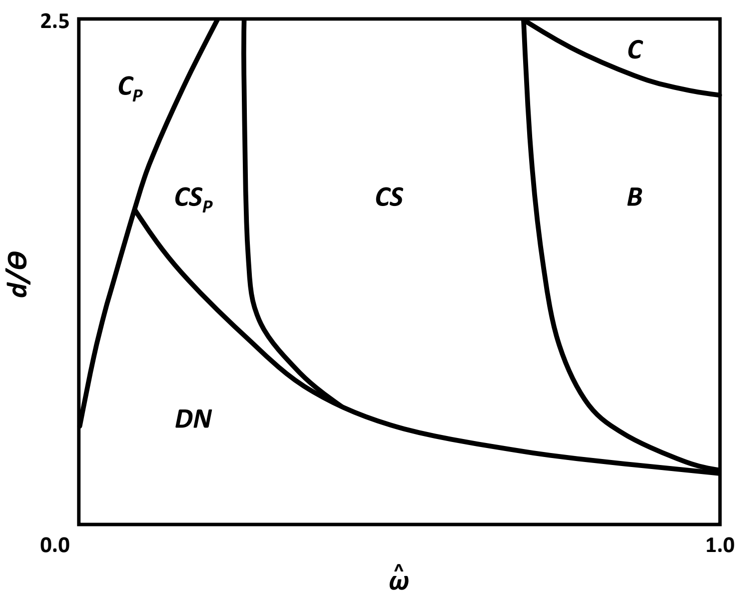


Figure 5 **GreenBlue's Equilibrium Strategy With Respect to $\hat{\omega}$ and d/θ**

Note: The values used to generate Figure 5 are identical to those used for Figure 3 but with d taking values from $[0.00, 1.00]$. The abbreviations represent Base Case (B), Cost Sharing with (CS_P) and without (CS) a premium, Competition with (C_P) and without (C) a premium, and Do Nothing (DN).

As shown in Figure 5, promoting MIQ as a tool to create competition between suppliers is GreenBlue's preferred strategy only when the relative market awareness of quality is very high and there exists a dominant entity in the supply chain (see Table A.5 in Appendix D.2). For these cases, the

[10] We do not model GreenBlue's potential revenue or cost from distributing MIQ. Our focus is strictly on how GreenBlue should encourage firms interact with suppliers through the MIQ platform. GreenBlue maintains and administers the MIQ platform and thus, has the ability to promote the proper usage of MIQ by partner firms.

existing supplier does not incur a loss in profit due to competition since d/θ is high. When the firm captures most of the supply chain margin (i.e., $\hat{\omega}$ is very low), the firm offers a premium to offset the supplier's unit cost of quality. When instead, the supplier captures most of the supply chain margin (i.e., $\hat{\omega}$ is very high), the supplier acts as if she is the single decision maker in the supply chain and her incentive to improve quality and thus, demand increases. Therefore, the firm does not offer a premium.

For a wide range of $\hat{\omega}$ values, GreenBlue's preferred strategy is to encourage the firm to share costs with his existing supplier and create an incentive for her to invest in quality. Although cost sharing can increase environmental quality while ensuring that the firm and the supplier do not lose profits, it rarely generates a higher quality level than supplier competition. For example, numerically we find that for cases in which GreenBlue's preferred strategy is cost sharing, the supplier's median quality level is 0.25 for cost sharing and 0.28 for cost sharing with a premium. For these same cases, median quality levels of 0.58 and 0.39 are achievable under supplier competition (see Table A.5 in Appendix D.2). However, competition is an infeasible strategy for these cases since the supplier incurs profits less than she would under the do nothing case. Furthermore, alignment between GreenBlue's objective to maximize quality and the firm's objective to maximize his profit typically does not occur under cost sharing. Only when d/θ is very high and the supplier's margin is low (in the CS region) do we find that cost sharing maximizes both quality and the firm's profit. In contrast, when supplier competition is GreenBlue's preferred strategy, it always aligns GreenBlue's and the firm's objectives.[11]

When the supplier's margin is very high, cost sharing is not an effective strategy since the firm is unwilling to share costs due to the supplier capturing most of the supply chain margin. As previously shown in Figure 3, the firm sets $\gamma^* = 1$ and as a result, $q^*_{CS}(\gamma^*) = q^*_B$. Competition can be an effective strategy, but only when there exists a market opportunity (i.e., d/θ is high) that helps the supplier to offset her cost due to competition. Instead, for a majority of the cases, GreenBlue's preferred strategy when $\hat{\omega}$ is high is to recommend the base case (without a premium) and to let the existing market incentives drive the supplier's quality decision and use of MIQ. Finally, if both the supplier's margin and the relative market awareness of quality are low, then GreenBlue's strategy is to not promote MIQ; i.e., the do nothing case. Under these conditions, GreenBlue cannot influence quality since the market opportunity is not strong enough to justify investment by the firm and/or the supplier.

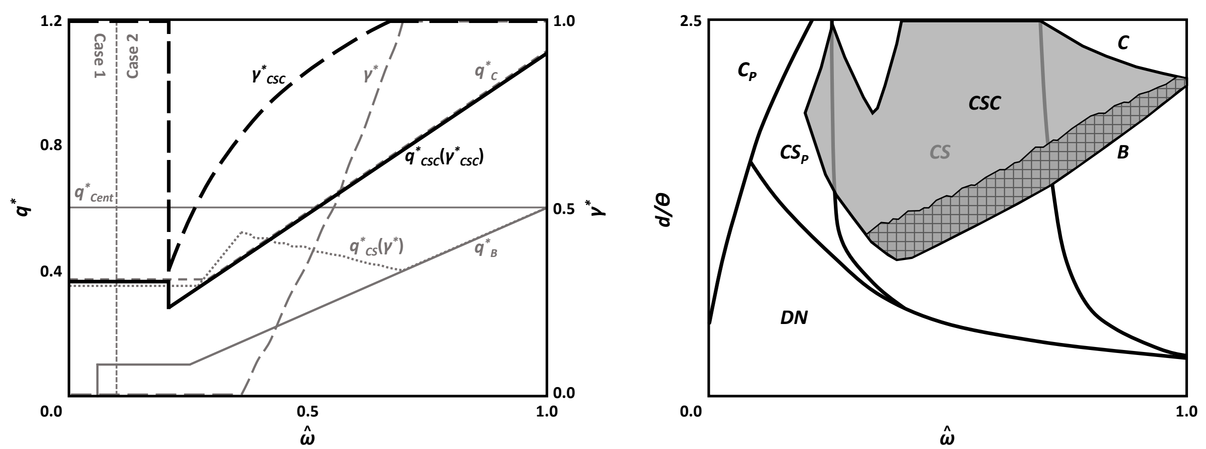
Cost-sharing Competition Dynamic: Of the three firm-supplier dynamics examined, supplier competition almost always induces the highest quality level. However, from GreenBlue's perspective, recommending that a firm use MIQ as a tool to create competition between suppliers is typically not a feasible strategy since it can hurt suppliers' profits. To identify ways for GreenBlue to incentivize the high quality levels that can occur when suppliers compete, we examine a new dynamic that incorporates both cost sharing and competition. Under this new dynamic, labeled cost-sharing competition

[11] GreenBlue and the firm's objectives align for only 11.8% of the 868,660 cases tested. For 2.6% of the cases tested, alignment occurs due to cost sharing. This occurs when d/θ is very high; i.e., the median $d/\theta > 4.0$.

(CSC), the two suppliers compete on quality, but with the firm offsetting the quality investment cost of the existing supplier to ensure that she does not incur a decrease in profits due to competition.

The sequence of events for cost-sharing competition is as follows. First, the firm determines the portion of the existing supplier's investment cost, $1-\gamma_{CSC}$, that he is willing to share. Second, the firm decides the per-unit premium, r_{CSC}, 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. After the two suppliers compete, the firm then sources from the supplier with the highest quality level; i.e., $q^*_{CSC}(\gamma^*_{CSC})$. See Appendix C for the structural form of q^*_{CSC} for a given r. A key difference between cost-sharing competition and cost sharing is that the firm does not solve for γ^*_{CSC} to solely maximize his profit. Instead, he is constrained by the fact that the supplier cannot earn less than she does under the do nothing case. For the parameter set tested, we consider cost-sharing competition infeasible if a $\gamma^*_{CSC} \in [0,1]$ cannot be found such that both the firm and the supplier earn profits greater than or equal to their profits under the do nothing case.

Figure 6(a) adds to Figure 3(b) the firm's choice of γ^*_{CSC} and the resulting quality level, $q^*_{CSC}(\gamma^*_{CSC})$, under cost-sharing competition. Figure 6(b) illustrates how GreenBlue's equilibrium strategy from Figure 5 changes when GreenBlue promotes cost-sharing competition as a potential way to use MIQ.



(a) (b)

Figure 6 Environmental Quality and GreenBlue's Equilibrium Strategy: Cost-Sharing Competition

Note: Figure 6(a) illustrates the firm's choice of γ^*_{CSC} and the resulting $q^*_{CSC}(\gamma^*_{CSC})$ for the values used to generate Figure 3(b). Figure 6(b) demonstrates GreenBlue's equilibrium strategy when cost-sharing competition is an option. The values used are identical to those used for Figure 5, with the additional abbreviation Cost-Sharing Competition (CSC). The hatched region in Figure 6(b) highlights when the firm does not incur an increase in profit due to cost-sharing competition.

Numerically we find that GreenBlue's preferred strategy is cost-sharing competition for 21.3% of the 868,660 cases tested (see Table A.6 in Appendix D.2). Cost-sharing competition is not an alternative for cases in which GreenBlue's strategy is supplier competition since it cannot induce quality levels greater than those under competition. Instead, GreenBlue should promote cost-sharing competition primarily for cases in which the relative market awareness of quality is high and it previously promoted either cost sharing without a premium (16.0% of the cases tested) or the base case without a premium (3.6% of the cases tested). Recall that under cost sharing, when the supplier's margin is high, the firm is not willing to share a large portion of the supplier's investment cost. As a result, the supplier's quality is either nonincreasing in $\hat{\omega}$ or equal to q_B^* (see Figure 3). Conversely, under competition, although the supplier's quality is nondecreasing in her margin (Proposition 3), the supplier's profit is often less than her profit under the do nothing case. By recommending cost-sharing competition, GreenBlue can incentivize the higher quality levels that occur when suppliers compete while ensuring that the supplier does not incur a decrease in profit. As shown in Figure 6(a), the supplier's quality under cost-sharing competition is often equal to or just less than the quality level achieved under competition.

Notice in Figure 6(b) that GreenBlue's preferred strategy is cost sharing and not cost-sharing competition for a range of $\hat{\omega}$ values when d/θ is high. Recall that $q_{CS}^*(\gamma^*)$ can be increasing in $\hat{\omega}$ for a range of the supplier's margin where the firm does not offer a premium but does fully or almost fully subsidize the supplier's investment cost (see Figure 6(a)). Within this range, the supplier's quality under cost sharing can be greater than her quality under supplier competition (see footnote 9), which we know is greater than or equal to her quality under cost-sharing competition. Therefore, in this region, GreenBlue's preferred strategy is cost sharing since it produces the highest supplier quality.

Finally, from a profit perspective, we find that the firm can often benefit from cost-sharing competition. For 72.8% of the cases in which GreenBlue's preferred strategy is to promote cost-sharing competition, the firm's profit is actually higher than his profit under his previously preferred strategy (see the non-hatched CSC region in Figure 6(b)). These cases occur for higher values of d/θ, when the firm can markedly increase his demand by offsetting the supplier's investment cost. The firm's profit does not typically decrease under cost-sharing competition in part because the firm's strategy for sharing costs is not to develop the supplier's capabilities (as previously seen in §4.3), but instead, only to stabilize the supplier's profits enough to ensure that she does not incur a loss in profits.[12] As shown in Figure 6(a) (see Table A.6 in Appendix D.2), γ_{CSC}^* is greater than γ^* and the firm typically shares less than half of the supplier's quality investment cost. We should emphasize that the use of cost-sharing competition is restricted to cases when d/θ is high. There must be a market opportunity for the firm to incur additional costs to offset the supplier's decrease in profits due to competition. If instead, d/θ is low, then a $\gamma_{CSC} \in [0,1]$ cannot be found such that both the firm's and the supplier's profits are greater under cost-sharing competition than the do nothing case.[13]

[12] Also for this reason, GreenBlue's preferred strategy is rarely for the firm to offer the supplier a premium under cost-sharing competition; see Table A.6 in Appendix D.

[13] Cost-sharing competition is often not feasible. For 60.9% of the 868,660 cases tested, a γ_{CSC}^* cannot be found that ensures both the firm and the supplier earn profits greater than or equal to their profits under the do nothing case.

6. Managerial Insights and Conclusion

Today there are almost 84,000 known chemicals in commercial use in the United States, with over 500 new chemicals introduced each year (U.S. Environmental Protection Agency 2014). For an alarming number of these substances, we are still unsure of their health and environmental impacts (Layton 2010, Rizzuto 2013). In the United States, even as public awareness of environmental hazards increases, proper regulations for monitoring and controlling chemical usage are still not in place. As Dr. Richard Denison, senior scientist at the Environmental Defense Fund, noted, "by failing to identify, let alone control, the long and growing list of chemicals in everyday products that we now know can harm people and the environment, [the U.S. Toxic Substances and Control Act] has forced states, businesses, workers and consumers to try to act on their own to address what should be a national priority" (Safer Chemicals Healthy Families 2010). Due to this lack of regulatory guidance, an opportunity exists for nonprofits to play an influential role in shaping firms' chemical management policies.

In this paper we examine Material IQ (MIQ), a new decision-tool developed by GreenBlue that helps suppliers to safely share sensitive toxicity and compliance data with their customers. As GreenBlue takes MIQ to market, it must determine when and how to promote the use of MIQ. We study GreenBlue's problem in two parts. First we investigate under what market and economic conditions a firm can utilize a per-unit premium, firm-supplier cost sharing, or supplier quality competition to improve a supplier's environmental quality. Based on our findings, we then develop insights into GreenBlue's strategy for promoting the use of MIQ. Our analysis yields valuable insights into how firms and nonprofits can improve the environmental performance of supply chains.

The firm's strategy: Our findings demonstrate how the division of the supply chain margin between a firm and a supplier influences the levers the firm can use to entice the supplier to invest in quality. For example, consider the *base case*, when the firm relies solely on a premium to incentivize the supplier to invest. We find that the supplier's quality level is nondecreasing in her margin. The firm's strategy is to offer the supplier a premium only if he captures a majority of the supply chain margin and a market opportunity exists for improved quality. If the supplier's margin is low and an opportunity does not exist, then the firm does not invest in the supplier (due to the size of the premium he would need to offer) and the supplier does not invest in quality. If instead, the supplier captures a large portion of the supply chain margin, then her decisions begin to mimic those of a single decision-maker attempting to increase demand and the firm does not need to offer her a premium. The firm can let the supplier invest on her own in quality, with her investment size increasing in the market opportunity.

Establishing a new dynamic between the firm and the supplier can help to improve the supplier's quality but with some limitations. For example, consider *cost sharing*.[14] The firm's use of a premium under cost sharing is similar to the base case. Only if he captures more of the supply chain margin than

[14] We focus our cost-sharing insights on the case in which the firm determines his portion of the shared investment cost.

the supplier and a market opportunity exists, does the firm benefit by offering the supplier a premium. The key difference between the two dynamics is the extent to which the firm invests in the supplier under cost sharing. If the firm offers the supplier a premium, then his optimal cost-sharing strategy is to also fully subsidize her investment cost in quality. By aggressively investing in the supplier, the firm develops her capabilities, and as a result, increases the effectiveness of his premium investment. Cost sharing, however, is less effective when the supplier's margin is high. Unlike the base case, the supplier's quality under cost sharing is no longer always nondecreasing in her margin. Instead, as the supplier's margin increases, the firm either decreases his portion of the shared investment cost or when the supplier captures a large portion of the supply chain margin, does not share costs. As a result, the supplier's quality level is close to or equal to her quality level under the base case.

Similar to the base case, under *supplier competition*, the supplier's quality level is nondecreasing in her portion of the supply chain margin. Unlike the base case and cost sharing, however, as long as the new supplier introduced is competitive on costs, the existing supplier always invests in quality. The firm may still benefit by offering the supplier a premium when her margin is low but the investment is only to further incentivize her to invest in quality. In general, the supplier's quality level is higher under competition than either the base case or cost sharing since competition forces the supplier to sacrifice her margin to invest in quality. In particular, when the supplier's margin is high, she has more flexibility to invest in quality and as a result, cases can occur under competition in which the supplier produces a quality level greater than the centralized solution. The key risk to supplier competition is the potential negative impact that it can have on suppliers' margins and thus, financial health.

GreenBlue's strategy: From GreenBlue's perspective, a firm using MIQ as a tool for creating competition between suppliers is often not a feasible strategy since it can hurt suppliers' profits. Only when consumers' awareness of quality is high and there exists either a dominant firm or supplier in the supply chain should GreenBlue recommend supplier competition as a strategy. Instead, if a firm captures enough of the supply chain margin such that he is willing to share costs with the supplier, then GreenBlue should recommend the firm use MIQ as a platform for collaborating with an existing supplier to improve quality.[15] Conversely, if the firm is unwilling to share costs with the supplier due to her high margin, then GreenBlue should recommend the firm let the existing market incentives drive the supplier's quality decision and use of MIQ.

Neither of the strategies mentioned above produce quality levels as high as those found under competition. Therefore, we investigate ways in which GreenBlue can promote the use of competition without hurting suppliers' profits. If the firm is willing to share costs with his existing supplier to ensure that she does not realize a decrease in profits due to competition, then GreenBlue should recommend

[15] We recognize that in our setting, there are additional challenges to collaboration that deserve further study. For example, the sizes of the firms and the suppliers may make collaboration difficult. In a survey of 45 firms conducted by the authors and GreenBlue, we found that 44.8% (6.3%) of companies with revenues greater (less) than \$1B are currently participating in collaborative chemicals management partnerships.

a combined strategy of supplier competition *and* cost sharing when the market awareness of quality is high. That is, when consumers are particularly sensitive to the chemicals in their products, GreenBlue should recommend a firm help his suppliers to implement MIQ so that they may compete as part of the marketplace. Interestingly, the firm can often incur an increase in profits from this combined strategy since his portion of the shared investment cost is often not substantial but can induce quality levels comparable to those realized under competition. A combined strategy, however, is not feasible when the market awareness of quality is low, as a division of the supplier's investment cost that mutually benefits both the supplier and the firm cannot be found.

GreenBlue is in a unique position in that it has an opportunity to influence the dynamic between firms and suppliers with MIQ. Our model illustrates both the potential benefits and risks that a nonprofit can face as it attempts to improve the environmental performance of a supply chain. For example, we find that although supplier competition can be very effective in improving a supplier's environmental performance, promoting its use may damage 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 firms, who lacked the resources to compete, out of business (Moorman et al. 2005).

In a survey of 45 firms conducted by the authors and GreenBlue (see Appendix §O.2 for the survey results), small, private suppliers were found to follow the poorest chemicals management practices. This suggests that as small suppliers incur costs to improve their chemicals 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 need to take a less aggressive approach in trying to improve the environmental performance of suppliers. Instead of recommending that firms use MIQ to solely create competition between suppliers, GreenBlue may want to focus on the more modest improvements that can occur when firms and suppliers work together in a collaborative relationship.

Appendix A: Equilibria

In this section, we discuss the detailed analysis regarding the firm's and the supplier's equilibrium strategies for the base case, cost sharing, and supplier competition dynamics. The firm's and the supplier's equilibrium profit functions are available from the authors upon request.

Analysis of the Base Case and Cost-Sharing: The analysis below is for the cost-sharing dynamic. The base case equilibrium can be found by setting $\gamma = 1$. We solve for the equilibrium r^* and q^* by backward induction. We start the analysis from the last stage; i.e., the supplier's quality investment decision given r. The supplier's problem is:

$$max_q \; \Pi_{CS}^S = (\theta + dq)[\hat{\omega} + (r - cq)] - \gamma y q^2$$

The first-order-condition of the expression above is $-2q(cd + \gamma y) - c\theta + d(r + \hat{\omega}) = 0$, and the second-order-condition is $-2(cd + \gamma y) < 0$, which guarantees that the objective function is concave in q. Thus, the supplier's best response quality given r is

$$q^*_{CS}(r) = \left(\frac{-c\theta + d(r+\hat{\omega})}{2(cd+y\gamma)}\right)^+ \tag{5}$$

Given the supplier's best response, the firm maximizes his own profit function; $max_r \ \ (\theta + dq^*(r))(\hat{p} - r) - (1-\gamma)yq^*(r)^2$. Note that when $q^*_{CS}(r) = q^o_{CS}(r) = \frac{-c\theta+d(r+\hat{\omega})}{2(cd+y\gamma)}$, the firm's profit function is concave in r as shown below:

$$\Pi^{Fo}_{CS} = \Pi^F_{CS}(r, q^o_{CS}(r)) = (\hat{p} - r)\left(\theta + \frac{d(-c\theta + d(r+\hat{\omega}))}{2(cd+y\gamma)}\right) - (1-\gamma)y\left(\frac{-c\theta + d(r+\hat{\omega})}{2(cd+y\gamma)}\right)^2$$

where FOC is $-\frac{c^2d^2\theta + cd(-d^2\hat{p} + 2d^2r + d^2\hat{\omega} - y\theta + 4\theta y\gamma) + y(2y\theta\gamma^2 + d^2r + d^2\hat{\omega} - d^2\hat{p}\gamma + d^2r\gamma)}{2(cd+y\gamma)^2}$ and SOC is $-\frac{d^2(2cd+y+y\gamma)}{2(cd+y\gamma)^2} < 0$. Then the maximizer of this function is $r^o_{CS} = \frac{cd^3(\hat{p}-\hat{\omega}) + d^2y(\hat{p}\gamma - \hat{\omega}) + cdy\theta(1-\gamma) - \theta(cd+2y\gamma)(cd+y\gamma)}{d^2(2cd+y(1+\gamma))}$. Based on these, we will characterize the firm's best response for two cases: (Case 1) $\frac{c}{\hat{\omega}} - \frac{d}{\theta} > 0$ and (Case 2) $\frac{c}{\hat{\omega}} - \frac{d}{\theta} \leq 0$.

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

$$\Pi^F_{CS} = \begin{cases} \theta(\hat{p} - r) & 0 \leq r < \frac{c\theta - d\hat{\omega}}{d} \\ \Pi^{Fo}_{CS} & r \geq \frac{c\theta - d\hat{\omega}}{d} \end{cases}$$

The firm's best response and the following supplier investment are:

$$(r^*, q^*) = \begin{cases} \left(r^o_{CS} = \frac{cd^3(\hat{p}-\hat{\omega}) + d^2y(\hat{p}\gamma-\hat{\omega}) + cdy\theta(1-\gamma) - \theta(cd+2y\gamma)(cd+y\gamma)}{d^2(2cd+y+y\gamma)}, q^o_{CS}(r^o_{CS}) = \frac{d^2(\hat{p}+\hat{\omega}) - \theta(2y\gamma+3cd)}{2d(2cd+y+y\gamma)}\right) \\ \quad if \ \ \hat{p} + \hat{\omega} \geq \frac{\theta(3cd+2y\gamma)}{d^2} \ \ and \ \ d^4(\hat{p}+\hat{\omega})^2 + 2d^2\theta\hat{\omega}(cd+2y) - 2d^2\theta\hat{p}(3cd+2y\gamma) \\ \qquad + 4\theta^2y^2\gamma^2 + 4cdy\theta^2(-1+2\gamma) + c^2d^2\theta^2 \geq 0 \\ \\ (0,0) \ otherwise \end{cases} \tag{6}$$

For the first line of the equilibrium, the first condition ensures that the maximizer r^o_{CS} is higher than the threshold $\frac{c\theta - d\hat{\omega}}{d}$, and the second condition ensures that $\Pi^F_{CS}(r^o_{CS}, q^*_{CS}(r^o_{CS})) \geq \Pi^F_{CS}(0,0)$.

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

$$(r^*, q^*) = \begin{cases} \left(r^o_{CS} = \frac{cd^3(\hat{p}-\hat{\omega}) + d^2y(\hat{p}\gamma-\hat{\omega}) + cdy\theta(1-\gamma) - \theta(cd+2y\gamma)(cd+y\gamma)}{d^2(2cd+y+y\gamma)}, q^o_{CS}(r^o_{CS}) = \frac{d^2(\hat{p}+\hat{\omega}) - \theta(2y\gamma+3cd)}{2d(2cd+y+y\gamma)}\right) \\ \quad if \ \ cd^3(\hat{p}-\hat{\omega}) + d^2y(\hat{p}\gamma - \hat{\omega}) - \theta(cd+2y\gamma)(cd+y\gamma) + cdy\theta(1-\gamma) \geq 0 \\ \\ \left(0, \frac{-c\theta+d\hat{\omega}}{2(cd+y\gamma)}\right) \ otherwise \end{cases} \tag{7}$$

The base case and cost-sharing equilibrium values are summarized in Table A.2.

Centralized Solution: As a benchmark, we study the optimal quality investment in the centralized system. The objective function of the centralized system would be $max_q \ (\theta + dq)(\hat{p} + \hat{\omega} - cq) - yq^2$ with the optimal quality $q^*_{Cent} = \left(\frac{d(\hat{p}+\hat{\omega}) - c\theta}{2(cd+y)}\right)^+$.

Analysis of Competition: The competition dynamic has two stages. First, the firm declares the unit premium r that he is willing to pay, and then the suppliers propose the quality level q_i that they are willing to build. The firm selects the supplier with the highest quality proposal and only

Table A.2 **Base Case and Cost-Sharing Equilibrium Results**

Case	Conditions	r_B^*	q_B^*
1	$\hat{p}+\hat{\omega} \geq \frac{\theta(3cd+2y)}{d^2}$ (Con_B^{1A}) and $E_B^\natural \geq 0$ (Con_B^{1B})	$\frac{1}{2}\left(\hat{p}-\hat{\omega}-\frac{(cd+2y)\theta}{d^2}\right)$	$\frac{-\theta(2y+3cd)+d^2(\hat{p}+\hat{\omega})}{4d(cd+y)}$
	otherwise	0	0
2	$\hat{p}-\hat{\omega} \geq \frac{\theta(cd+2y)}{d^2}$ (Con_B^2)	$\frac{1}{2}\left(\hat{p}-\hat{\omega}-\frac{(cd+2y)\theta}{d^2}\right)$	$\frac{-\theta(2y+3cd)+d^2(\hat{p}+\hat{\omega})}{4d(cd+y)}$
	otherwise	0	$\frac{-c\theta+d\hat{\omega}}{2(cd+y)}$
Case	**Conditions**	r_{CS}^*	q_{CS}^*
1	$\hat{p}+\hat{\omega} \geq \frac{\theta(3cd+2y\gamma)}{d^2}$ (Con_{CS}^{1A}) and ${E_{CS}^1}^\dagger \geq 0$ (Con_{CS}^{1B})	$\frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}\gamma-\hat{\omega})}{d^2(cd+y(1+\gamma))} + \frac{cdy\theta(1-\gamma)-\theta(cd+2y\gamma)(cd+y\gamma)}{d^2(cd+y(1+\gamma))}$	$\frac{d^2(\hat{p}+\hat{\omega})-\theta(2y\gamma+3cd)}{2d(2cd+y(1+\gamma))}$
	otherwise	0	0
2	${E_{CS}^2}^\ddagger \geq 0$ (Con_{CS}^2)	$\frac{cd^3(\hat{p}-\hat{\omega})+d^2y(\hat{p}\gamma-\hat{\omega})}{d^2(cd+y+y\gamma)} + \frac{cdy\theta(1-\gamma)-\theta(cd+2y\gamma)(cd+y\gamma)}{d^2(cd+y(1+\gamma))}$	$\frac{d^2(\hat{p}+\hat{\omega})-\theta(2y\gamma+3cd)}{2d(2cd+y(1+\gamma))}$
	otherwise	0	$\frac{d\hat{\omega}-c\theta}{2(cd+y\gamma)}$

$\natural$ $E_B = \theta^2(2y+cd)^2 - 2d^2\theta\left((2y+3cd)\hat{p}-(2y+cd)\hat{\omega}\right) + d^4(\hat{p}+\hat{\omega})^2$
$\dagger$ $E_{CS}^1 = d^4(\hat{p}+\hat{\omega})^2 + 2d^2\theta\hat{\omega}(cd+2y) - 2d^2\theta\hat{p}(3cd+2y\gamma) + 4\theta^2y^2\gamma^2 + 4cdy\theta^2(-1+2\gamma) + c^2d^2\theta^2 \geq 0$
$\ddagger$ $E_{CS}^2 = cd^3(\hat{p}-\hat{\omega}) + d^2y(\hat{p}\gamma-\hat{\omega}) - \theta(cd+2y\gamma)(cd+y\gamma) + cdy\theta(1-\gamma)$

works with her. Here, we assume that *the firm prefers the low-cost supplier (supplier 1) whenever he is indifferent ($q_1 = q_2$)*. We also assume that *supplier 1 is strong enough to nudge the competition to the lowest-quality equilibria.*

Suppliers' Competition: First, for a given r, we define quality thresholds $\bar{q}_1$, $\bar{q}_2$, and q_1^* such that

$$\Pi^{S_1}(r,\bar{q}_1) = (\theta + d\bar{q}_1)(\hat{\omega} + r - c\bar{q}_1) - y\bar{q}_1^2 = 0 \tag{8}$$
$$\Pi^{S_2}(r,\bar{q}_2) = (\theta + d\bar{q}_2)(\hat{\omega} + r - \bar{c}\bar{q}_2) - y\bar{q}_2^2 = 0 \tag{9}$$
$$q_1^* = argmax_q \; \Pi^{S_1}(r,q) \tag{10}$$

Note first that for a given (r,q), $\Pi^{S_1}(r,q) \geq \Pi^{S_2}(r,q)$ since $\bar{c} \geq c$. By concavity of the supplier profit function with respect to q, we can conclude that $\bar{q}_1 \geq \bar{q}_2$ for a given r.

Theorem A.1. *Given premium r, for all $q\epsilon[max(\bar{q}_2, q_1^*), \bar{q}_1]$, (q,q) is an equilibrium of the supplier competition game. In addition, $(q_1^*, [0, q_1^*])$ constitutes equilibria when $\bar{q}_2 < q_1^*$. In any equilibrium, supplier 1 is selected by the firm and the minimum quality level built in the market is $max(\bar{q}_2, q_1^*)$.*

Proof of Theorem A.1: Here, we do the proof by considering four cases.

(i) *There does not exist an equilibrium where $q_i > \bar{q}_1$ is played.* Suppose that supplier 1 sets $q_1 > \bar{q}_1$. Supplier 2's best response to that would be $[0, q_1]$. However, under these conditions, supplier 1 would be better off with $[0, q_2)$ (where she would generate zero profit instead of incurring a loss) or $max(q_2, q_1^*)$ when $q_2 < \bar{q}_1$ (where it is actually possible to earn a positive profit). Similarly, suppose now that supplier 2 sets $q_2 > \bar{q}_1$. Supplier 1's best response to that would be $[0, q_2)$. Then supplier 2 would be better off with $q_2 \in [0, q_1]$.

(ii) *There does not exist an equilibrium where $q < max(\bar{q}_2, q_1^*)$ is played except when $\bar{q}_2 < q_1^*$ and is played by supplier 2.* We will consider two sub-cases in this analysis:

— $q_1^* \leq \bar{q}_2$: Here we consider the cases where $q < \bar{q}_2$. Suppose that supplier 1 sets $q_1 < \bar{q}_2$. If $q_1 < q_2$, then supplier 1 would be better off if she increased q_1 to q_2. If $q_1 \geq q_2$, then supplier 2 would be better off if she increased q_2. Now suppose we have $q_2 < \bar{q}_2$. If $q_1 < q_2$, then supplier 1 would be better off with a higher q_1 such that $q_1 \geq q_2$. If $q_1 \geq q_2$, we can consider two cases. When $q_1 \geq \bar{q}_2 > q_2$, then supplier 1 has an incentive to decrease q_1. When $\bar{q}_2 > q_1 \geq q_2$, then supplier 2 will be better off if she increases q_2 such that $\bar{q}_2 > q_2 > q_1$.

— $\bar{q}_2 < q_1^*$: Here we consider the cases where $q < q_1^*$. Suppose that supplier 1 sets $q_1 < q_1^*$. If $q_1 < q_2$, then supplier 1 has an incentive to increase quality to at least q_2. If $q_1 \geq q_2$, then supplier 1 has an incentive to increase to q_1^*. Suppose now that supplier 2 sets $q_2 < q_1^*$. Here supplier 1's best response to q_2 such that $q_2 \leq q_1^*$ would be q_1^*. Given that supplier 1 sets q_1^*, supplier 2's best response would be $[0, q_1^*]$. Then $(q_1^*, [0, q_1^*])$ constitutes an equilibrium if $\bar{q}_2 < q_1^*$.

(iii) *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.

(iv) *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. Thus, (q, q) is an equilibrium. ■

By our assumptions and by Theorem A.1, the quality level at the supplier competition stage for a given r is:

$$max\left[\left(\frac{d(r+\hat{\omega})-c\theta}{2(cd+y)}\right)^+, \frac{\sqrt{(d(r+\hat{\omega})+\bar{c}\theta)^2+4y\theta(r+\hat{\omega})}+d(r+\hat{\omega})-\bar{c}\theta}{2(y+\bar{c}d)}\right] \tag{11}$$

Lemma A.1. *If $d(2c-\bar{c})+y \geq 0$ holds, then $\bar{q}_2 \geq q_1^*$ as defined in Equations 9 and 10; i.e., the competitor's position drives supplier 1's best response to the offered premium r under competition.*

Proof of Lemma A.1: $\bar{q}_2 \geq q_1^*$ automatically holds when we have $d(r+\hat{\omega})-c\theta < 0$. For the case $d(r+\hat{\omega})-c\theta \geq 0$, the relationship $\bar{q}_2 \geq q_1^*$ is equivalent to:

$$\begin{aligned}
&\frac{\sqrt{(d(r+\hat{\omega})+\bar{c}\theta)^2+4y\theta(r+\hat{\omega})}+d(r+\hat{\omega})-\bar{c}\theta}{2(\bar{c}d+y)} \geq_? \frac{d(r+\hat{\omega})-c\theta}{2(cd+y)}\\
&(cd+y)\sqrt{(d(r+\hat{\omega})+\bar{c}\theta)^2+4y\theta(r+\hat{\omega})}+(cd+y)(d(r+\hat{\omega})-\bar{c}\theta) \geq_? (\bar{c}d+y)(d(r+\hat{\omega})-c\theta)\\
&(cd+y)\sqrt{(d(r+\hat{\omega})+\bar{c}\theta)^2+4y\theta(r+\hat{\omega})}-(\bar{c}-c)(d^2(r+\hat{\omega})+y\theta) \geq_? 0
\end{aligned} \tag{12}$$

Below we define a simpler yet more restricted version of condition 12:

$$\begin{aligned}
(cd+y)\sqrt{(d(r+\hat{\omega})+\bar{c}\theta)^2}-(\bar{c}-c)(d^2(r+\hat{\omega})+y\theta) &\geq 0\\
\Rightarrow d(r+\hat{\omega})[d(2c-\bar{c})+y]+c\theta(y+\bar{c}d) &\geq 0
\end{aligned} \tag{13}$$

Note that whenever condition 13 is satisfied, 12 automatically holds. Condition 13 is satisfied for all $\hat{\omega}, r \geq 0$ values whenever $d(2c-\bar{c})+y \geq 0$. ■

Thus, by our assumption $d(2c-\bar{c})+y \geq 0$ and Lemma A.1 above, $\bar{q}_2$ will be the best response to any $r \geq 0$.

Firm's Problem: Given the best response from the supplier competition stage, the firm maximizes his own profit is $max_{r\geq 0}\ (\theta + d\bar{q}_2(r))(\hat{p} - r)$. Note that the second order condition of the profit function above is given by:

$$SOC: \quad -\frac{d^5(r+\hat{\omega})^3 + 2dy\theta^2(\bar{c}^2\theta + yE_1) + d^4(r+\hat{\omega})^2(3\bar{c}\theta + E_2)}{(\bar{c}d+y)(E_2)^3} - \frac{d^2\theta(\bar{c}^3\theta^2 + 2cy\theta E_1 + \bar{c}^2\theta E_2 + 4y(r+\hat{\omega})E_2)}{(\bar{c}d+y)(E_2)^3} - \frac{d^3\theta(r+\hat{\omega})(6y(r+\hat{\omega}) + \bar{c}(3\bar{c}\theta + 2E_2))}{(\bar{c}d+y)(E_2)^3} < 0$$

where $E_1 = \hat{p} + 3r + 4\hat{\omega}$ and $E_2 = \sqrt{(d(r+\hat{\omega}) + c\theta)^2 + 4y\theta(r+\hat{\omega})}$. Since all terms in the expression above are negative (the numerator is negative whereas the denominator is positive), we conclude that the firm's objective function is concave. The maximizer of the profit function above is:

$$r^* = \left(\frac{d^2\hat{p}^2 - (d\hat{\omega} + \bar{c}\theta)^2 - 4y\theta\hat{\omega}}{2(\theta(\bar{c}d+2y) + d^2(\hat{p}+\hat{\omega}))}\right)^+ \tag{14}$$

Thus, when suppliers compete, the firm is willing to offer a positive premium if and only if $d^2\hat{p}^2 - (d\hat{\omega} + \bar{c}\theta)^2 - 4y\theta\hat{\omega} > 0$. That is, when $\hat{p}$ and d are substantially high compared to $\hat{\omega}$, y, $\bar{c}$, and θ. Thus, depending on the conditions, the firm either offers a zero premium or $r^o = \frac{d^2\hat{p}^2 - (d\hat{\omega}+\bar{c}\theta)^2 - 4y\theta\hat{\omega}}{2(\theta(\bar{c}d+2y)+d^2(\hat{p}+\hat{\omega}))} > 0$. The quality resulting from the supplier competition stage is as follows:

$$q_C^*(r^o) = q_C^o = \frac{d(\hat{p}+\hat{\omega}) - \bar{c}\theta}{2(\bar{c}d+y)}$$
$$q_C^*(0) = \frac{d\hat{\omega} - \bar{c}\theta + \sqrt{(d\hat{\omega}+\bar{c}\theta)^2 + 4y\theta\hat{\omega}}}{2(\bar{c}d+y)}$$

Thus, by our assumptions and by Theorem A.1, the equilibrium premium and quality investment levels under competition are as follows:

$$(r^*, q^*) = \begin{cases} \left(r_C^o = \frac{d^2\hat{p}^2 - (d\hat{\omega}+\bar{c}\theta)^2 - 4y\theta\hat{\omega}}{2(\theta(\bar{c}d+2y)+d^2(\hat{p}+\hat{\omega}))}, q_C^o = \frac{d(\hat{p}+\hat{\omega})-\bar{c}\theta}{2(\bar{c}d+y)}\right) & if\ d^2\hat{p}^2 - (d\hat{\omega}+\bar{c}\theta)^2 - 4y\theta\hat{\omega} \geq 0 \\ \left(0, \frac{d\hat{\omega} - \bar{c}\theta + \sqrt{(d\hat{\omega}+\bar{c}\theta)^2 + 4y\theta\hat{\omega}}}{2(\bar{c}d+y)}\right) & otherwise \end{cases} \tag{15}$$

Note that the firm offers a positive premium only when $d^2\hat{p}^2 - (d\hat{\omega} + \bar{c}\theta)^2 - 4y\theta\hat{\omega} \geq 0$ holds, which means that we must have at least $d^2\hat{p}^2 - (\bar{c}\theta)^2 \geq 0$. This guarantees that the resulting quality level under this case will be nonnegative.

Appendix B: Summary of Additional Theoretical Results

PROPOSITION A.1. *For the base case, supplier competition, and cost sharing, when the firm offers a premium to the supplier,*

(i) The resulting quality level is independent of the supplier's margin,

(ii) The premium is decreasing in the supplier's margin.

LEMMA A.2. *Under Case 2 ($\frac{d}{\theta} \geq \frac{c}{\hat{\omega}}$), the firm does not provide a premium unless*

(i) $\hat{p} - \hat{\omega} \geq \frac{\theta(cd+2y)}{d^2}$ under the base case,

(ii) $\hat{p} - \hat{\omega} \geq \frac{\theta(cd+2y\gamma)}{d^2}$ under cost sharing, and

(iii) $\hat{p} - \hat{\omega} \geq \frac{\bar{c}\theta}{d}$ under competition.

Proposition A.2. *[Supplier] Under cost-sharing, 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.*

Proposition A.3. *[Firm] Under cost-sharing, the firm offers a premium to the supplier to invest in quality when either:*
(i) The supplier will not invest without a premium (Case 1), there exists an $r > 0$ such that the firm incurs a higher profit paying a premium versus doing nothing (i.e., $r = 0$, $q = 0$), and $\frac{d(\hat{p}+\hat{\omega})}{\theta} > \frac{3cd+2y\gamma}{d}$.
(ii) The supplier will invest without a premium (Case 2) and $\frac{d(\hat{p}-\hat{\omega})}{\theta} + \frac{y(\hat{p}\gamma-\hat{\omega})}{c\theta} \geq \frac{cd+4y\gamma}{d} - \frac{y}{cd}(\frac{cd-2y\gamma^2}{d})$.

Lemma A.3. *Define $\hat{\omega}_B^{min}$ and $\hat{\omega}_{CS}^{min}$ as the minimum supplier margins for which the firm offers a premium to the supplier under the base case and cost sharing. Under these dynamics, if the supplier will not invest without a premium (i.e., $\frac{d}{\theta} < \frac{c}{\hat{\omega}}$) and the firm offers a premium, then $\hat{\omega}_{CS}^{min} \leq \hat{\omega}_B^{min}$.*

Lemma A.4. *(i) When $r_B^* > 0$, we have $q_B^* = q_B^o \leq q_{Cent}^*$,*
(ii) When $r_{CS}^* > 0$, we have $q_{CS}^* = q_{CS}^o \leq q_{Cent}^*$,
(iii) When $r_C^* > 0$, we have $q_C^* = q_C^o \leq q_{Cent}^*$.

Lemma A.5. *(i) q_C^* is nonincreasing in $\bar{c}$, and (ii) q_{CS}^* is nonincreasing in γ.*

Lemma A.6. *Under Case 2, as γ increases, the firm's strategies will be one of the five following:*
(i) no premium for all γ, $0 \leq \gamma \leq 1$,
(ii) premium for all γ, $0 \leq \gamma \leq 1$,
(iii) premium for $0 \leq \gamma \leq \dot{\gamma}$ and no-premium for $\dot{\gamma} \leq \gamma \leq 1$ for some $\dot{\gamma}$,
(iv) no premium for $0 \leq \gamma \leq \dot{\gamma}$ and premium for $\dot{\gamma} \leq \gamma \leq 1$ for some $\dot{\gamma}$,
(v) no premium for $0 \leq \gamma \leq \dot{\gamma}$, premium for $\dot{\gamma} \leq \gamma \leq \ddot{\gamma}$, and no-premium for $\ddot{\gamma} \leq \gamma \leq 1$, for some $\dot{\gamma}$ and $\ddot{\gamma}$.

Appendix C: Analysis of the Cost-Sharing Competition Dynamic

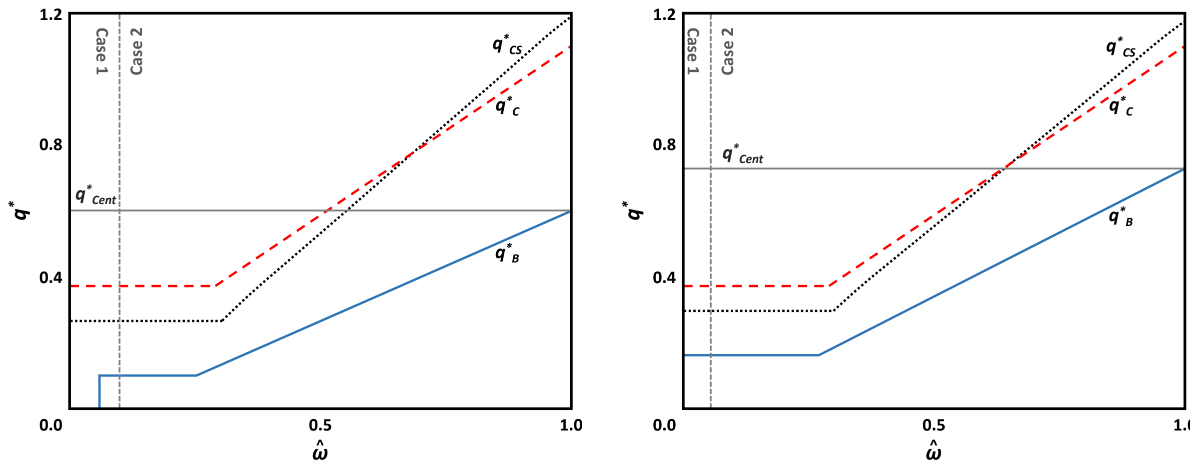
Under cost-sharing competition, the suppliers differ not only in terms of their unit quality cost (i.e., c vs. $\bar{c}$) but also in terms of the quality investment cost that they incur. The existing supplier's cost becomes $\gamma y q_1^2$ whereas the second supplier still incurs yq_2^2. Given this setup, for a given premium r, the competition follows similarly to that under the competition dynamic. Thus, the competition stage results in quality level:

$$max\left[\left(\frac{d(r+\hat{\omega})-c\theta}{2(cd+y\gamma_{CSC})}\right)^+, \frac{\sqrt{(d(r+\hat{\omega})+\bar{c}\theta)^2+4y\theta(r+\hat{\omega})}+d(r+\hat{\omega})-\bar{c}\theta}{2(y+\bar{c}d)}\right]$$

The left-hand-side term assures that the existing supplier invests at least as much as she would if she were only considering a cost-sharing agreement (without competition). The right-hand-side term assures that the incumbent invests enough to win the bid and drive the other supplier out.

Appendix D: Numerical Analysis

Next, we present our numerical analysis for §4 and §5. First, Figure 7 applies the same parameter set used to generate Figure 2 to highlight conditions under which $q^*_{CS} > q^*_C$ when $\gamma = 0.25$ (Figure 7(a)) or $c = 0.15$ (Figure 7(b)).



(a) $\boldsymbol{\gamma} = 0.25$, $\boldsymbol{c} = 0.25$ (b) $\boldsymbol{\gamma} = 0.5$, $\boldsymbol{c} = 0.15$

Figure 7 Environmental Quality With Respect to the Supplier's Margin

Note: The following values were used to generate Figure 7, $k = 1.00$, $a = 0.60$, $p = 1.00$, $y = 0.50$, $d = 1.00$, and $\bar{c} = 0.55$.

For Table A.3 (given γ case), we use the following parameter set: $c \in [0.05, 0.50]$, $\bar{c} \in [0.10, 0.55]$, $\hat{\omega} \in [0.05, 0.95]$, and $d \in [0.05, 0.95]$ all with an increment of 0.075; $y \in [0.10, 1.00]$ with an increment of 0.225, $a \in [0.05, 0.95]$ with an increment of 0.15, and $\gamma \in [0.00, 1.00]$ with an increment of 0.25. For Tables A.4 - A.6 we use the following parameter set: $c \in [0.05, 0.50]$ and $\bar{c} \in [0.10, 0.55]$ with an increment of 0.05; $\hat{\omega} \in [0.05, 0.95]$, $a \in [0.05, 0.95]$, and $d \in [0.05, 0.95]$ all with an increment of 0.075; and $y \in [0.10, 1.00]$ with an increment of 0.15. Subscript P denotes cases in which the firm offers the supplier a premium. Term q_{Max} represents the highest achievable quality under any of the dynamics.

D.1. The Firm's Strategy

Table A.3 defines the conditions under which the supplier's environmental quality is greater under cost sharing or competition for a given γ. Table A.4 defines how q^*_{CS} changes with respect to $\hat{\omega}$ when the firm solves for γ^*.

Table A.3 Firm-Supplier Dynamic With the Highest Environmental Quality For a Given γ

Strategy	Total Cases	% of Cases	$\hat{\omega}$	d/θ	γ	$\bar{c}/c$
CS_P	6,841	0.9%	0.13 [0.05,0.43]	2.07 [0.29,19.00]	0.00 [0.00,0.75]	4.40 [2.38,11.00]
CS	113,331	14.2%	0.65 [0.05,0.95]	1.75 [0.06,19.00]	0.00 [0.00,0.75]	3.20 [1.10,11.00]
C_P	101,401	12.7%	0.13 [0.05,0.43]	2.50 [0.21,19.00]	0.50 [0.00,1.00]	1.73 [1.10,11.00]
C	574,677	72.2%	0.58 [0.05,0.95]	0.79 [0.05,19.00]	0.50 [0.00,1.00]	2.00 [1.10,11.00]

Note: Values shown are Median [Min, Max]. Total number of cases tested are 796,250.

Table A.4 How q^*_{CS} Changes With Respect to $\hat{\omega}$ When the Firm Solves for γ^*

Case	Premium	q^*_{CS} w.r.t $\hat{\omega}$	Total Cases	q^*_{CS}	$\hat{\omega}$	γ^*
1	No	–	231,709	0.00 [0.00,0.00]	0.28 [0.05,0.95]	0.00 [0.00,0.00]
1	Yes	Constant	23,973	0.26 [0.00,1.95]	0.05 [0.05,0.28]	0.00 [0.00,0.00]
2	Yes	Nondec.	53,756	0.35 [0.02,2.42]	0.13 [0.05,0.43]	0.00 [0.00,0.04]
2	No	Dec.	267,104	0.26 [0.00,2.68]	0.58 [0.13,0.95]	0.54 [0.00,1.00]
		Nondec.	292,118	0.29 [0.00,3.05]	0.80 [0.05,0.95]	1.00 [0.00,1.00]

Note: Values shown are Median [Min, Max]. Total number of cases tested are 868,660. The Premium column denotes cases under which the firm's optimal strategy is to offer the supplier a premium.

D.2. GreenBlue's Strategy

Table A.5 defines GreenBlue's quality-maximizing strategy by $\hat{\omega}$ and d/θ. Table A.6 defines GreenBlue's strategy when we incorporate cost-sharing competition.

Table A.5 GreenBlue Strategy

Strategy	Total Cases	% of Cases	q_{GB}	q_{Max}	$\hat{\omega}$	d/θ
CS_P	58,902	6.8%	0.28 [0.00,2.42]	0.39 [0.04,2.42]	0.13 [0.05,0.43]	1.65 [0.18,19.00]
CS	339,389	39.1%	0.25 [0.00,2.72]	0.58 [0.07,3.38]	0.50 [0.05,0.95]	1.13 [0.06,19.00]
C_P	26,283	3.0%	0.49 [0.10,2.42]	0.49 [0.10,2.42]	0.05 [0.05,0.43]	2.91 [0.29,19.00]
C	54,247	6.2%	1.03 [0.23,5.06]	1.03 [0.23,5.06]	0.80 [0.35,0.95]	3.40 [0.28,19.00]
B	162,792	18.7%	0.25 [0.00,2.17]	0.88 [0.19,4.41]	0.88 [0.73,0.95]	1.10 [0.06,19.00]
DN	227,047	26.1%	0.00 [0.00,0.00]	0.40 [0.04,2.71]	0.28 [0.05,0.95]	0.35 [0.05,4.00]

Note: Values shown are Median [Min, Max]. Total number of cases tested are 868,660. Note that the γ^* Median [Min, Max] values for strategies CS_P and CS are 0.00 [0.00,0.04] and 0.32 [0.00,0.98].

Table A.6 GreenBlue Strategy: Incorporating the Cost-sharing Competition Dynamic

Strategy Orig.	Strategy New	Total Cases	% of Cases	Orig. q_{GB}	Orig. q_{Max}	Orig. π^F	New q_{GB}	New π^F
CS_P	CS_P	47,293	5.4%	0.28 [0.00,2.42]	0.39 [0.04,2.42]	0.46 [0.04,1.74]	0.28 [0.00,2.42]	0.46 [0.04,1.74]
CS	CS	200,365	23.1%	0.18 [0.00,2.72]	0.61 [0.06,2.72]	0.26 [0.01,1.73]	0.18 [0.00,2.72]	0.26 [0.01,1.73]
CS	CSC	138,899	16.0%	0.31 [0.05,2.33]	0.54 [0.07,3.38]	0.29 [0.02,1.32]	0.54 [0.07,3.38]	0.31 [0.02,1.70]
B	B	130,719	15.0%	0.22 [0.00,1.95]	0.88 [0.19,4.22]	0.06 [0.00,0.42]	0.22 [0.00,1.95]	0.06 [0.00,0.42]
B	CSC	31,204	3.6%	0.39 [0.10,2.17]	0.90 [0.27,4.41]	0.11 [0.01,0.66]	0.90 [0.27,4.41]	0.12 [0.00,1.02]
DN	DN	224,975	25.9%	0.00 [0.00,0.00]	0.40 [0.04,2.71]	0.40 [0.01,0.90]	0.00 [0.00,0.00]	0.40 [0.01,0.90]

Strategy Orig.	Strategy New	Total Cases	% of Cases	$\hat{\omega}$	d/θ	γ^*	γ^*_{CSC}
CS_P	CS_P	47,293	5.4%	0.13 [0.05,0.35]	1.46 [0.18,19.00]	0.00 [0.00,0.03]	–
CS	CS	200,365	23.1%	0.50 [0.05,0.95]	0.92 [0.06,19.00]	0.27 [0.00,1.00]	–
CS	CSC	138,899	16.0%	0.43 [0.13,0.80]	1.60 [0.13,19.00]	0.38 [0.00,1.00]	0.50 [0.00,1.00]
B	B	130,719	15.0%	0.88 [0.73,0.95]	1.00 [0.06,19.00]	1.00 [1.00,1.00]	–
B	CSC	31,204	3.6%	0.80 [0.73,0.95]	2.50 [0.21,19.00]	1.00 [1.00,1.00]	0.86 [0.00,1.00]
DN	DN	224,975	25.9%	0.28 [0.05,0.95]	0.35 [0.05,4.00]	0.00 [0.00,0.00]	–

Note: Values shown are Median [Min, Max]. Total number of cases tested are 868,660; 80,424 competition cases are not shown since competition dominates cost-sharing competition as a dynamic. 98.3% of all the remaining cases are presented. Only cases in which CS_P is replaced by CSC_P or CSC, CS is replaced by CSC, or DN is replaced by CSC_P are not shown. The γ^*_{CSC} values are shown only for cases in which GreenBlue's optimal strategy is CSC; for other cases, CSC may not be a feasible strategy.

References

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.

Balcik, B., B.M. Beamon. 2008. Facility location in humanitarian relief. *International Journal of Logistics Research and Applications* **11**(2) 101–121.

Banker, R.D., I. Khosla, K.K. Sinha. 1998. Quality and competition. *Management Science* **44**(9) 1179–1192.

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.

Berenguer, G., A. Righter, M. Shen. 2014. Challenges and strategies in managing nonprofit operations: An OR/MS perspective. Working paper, Purdue University, West Lafayette, IN.

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.

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.

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.

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.

Ekici, A., P. Keskinocak, J.L. Swann. 2014. Modeling influenza pandemic and planning food distribution. *Manufacturing & Service Operations Management* **16**(1) 11–27.

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

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.

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. 2014. The impact of supply chain structure on responsible sourcing. Working paper, Stanford University, Stanford, CA.

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.

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

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.

Karaer, Ö., F. Erhun. 2015. Quality and entry deterrence. *European Journal of Operational Research* **240**(1) 292–303.

Karmarkar, U.S., R.C. Pitbladdo. 1997. Quality, class and competition. *Management Science* **43**(1) 27–39.

Kaya, M., Ö. Özer. 2009. Quality Risk in Outsourcing: Noncontractible Quality and Private Quality Cost Information. *Naval Research Logistics* **56** 669–685.

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.

Laseter, T.M., W.F. Stasior. 1998. *Balanced sourcing: Cooperation and competition in supplier relationships*. Jossey-Bass Publishers.

Layton, L. 2010. Law allows companies to hide risks of chemicals. WashingtonPost.com (retrieved: Aug. 7, 2013), Jan. 4.

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. Second sourcing vs. sole sourcing with capacity investment and asymmetric information. *Manufacturing & Service Operations Management* **11**(3) 448–470.

Li, H., H. Zhang, C.H. Fine. 2013. Dynamic business share allocation in a supply chain with competing suppliers. *Operations Research* **61**(2) 280–297.

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.

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.

Moorthy, K.S. 1988. Product and price competition in a duopoly. *Marketing Science* **7**(2) 141–168.

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

Plambeck, E., T. Taylor. 2015. Supplier evasion of a buyer's audit: Implications for auditing and compliance with labor and environmental standards. Working paper, Stanford University, Stanford, CA.

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.

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

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

Rizzuto, P. 2013. TSCA reform bill seen as promising but road to enactment is uncertain. BNA.com (retrieved: Sept. 6, 2013), June 3.

Rosenbloom, S. 2009. At Wal-Mart, labeling to reflect green intent. NYTimes.com (retrieved: Aug. 3, 2013), July 15.

Safer Chemicals Healthy Families. 2010. The business case for comprehensive TSCA reform. SaferChemicals.org (retrieved: May 20, 2011).

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.

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.

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

Tsay, A., N. Agrawal. 2000. Channel dynamics under price and service competition. *Manufacturing & Service Operations Management* **2**(4) 372–391.

U.S. Environmental Protection Agency. 2014. TSCA chemical substance inventory. www.epa.gov (retrieved: Dec. 23, 2014).

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

Weisbrod, B. 1998. Modeling the nonprofit organization as a multiproduct firm: A framework for choice. B. Weisbrod, ed., *To Profit or Not to Profit: The Commercial Transformation of the Nonprofit Sector*. Cambridge University Press, Cambridge, 47–64.

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