Supplemental Information for ARCS Conference Paper Submission

1. **Paper Title:** Measurement and Improvement of Social and Environmental Performance under Voluntary versus Mandatory Disclosure

2. **Filename:** Ang.pdf

3. **Author names & Affiliations:**

    a. Basak Kalkanci (MIT – Engineering Systems Division)
    b. Erjie Ang (Stanford GSB – OIT)
    c. Erica Plambeck (Stanford GSB – OIT)

4. **Presenter Name:** Erjie Ang

5. **Primary Contact:** Erjie Ang (tel: 6073425120, email: erjieang@stanford.edu)

6. **Topic:** Social and Environmental Impacts in Supply Chains, Discretionary Disclosure, Experimental Surveys

7. **Preferences:** Please consider my paper for a presentation slot

8. **Topic:**
    a. Management/Strategy: Economics Oriented
    b. Marketing
    c. Operations/Supply Chain
    d. Public Policy

9. **Method:**
    a. Analytical Model
    b. Other: Experimental

Submitted to *Management Science*
manuscript

Measurement and Improvement of Social and Environmental Performance under Voluntary versus Mandatory Disclosure

Basak Kalkanci
Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA 02139, kalkanci@mit.edu

Erjie Ang
Graduate School of Business, Stanford University, Stanford, CA 94305, erjieang@stanford.edu

Erica Plambeck
Graduate School of Business, Stanford University, Stanford, CA 94305, elp@stanford.edu

Governments are beginning to mandate that firms disclose information about social and environmental impacts in their supply chains (e.g., regarding conflict minerals and greenhouse gas emissions). This paper shows that such a mandate will deter firms from measuring (and thus improving) those impacts, for two reasons. First, as demonstrated by our consumer choice experiments, voluntary disclosure of impacts can boost a firm's market share. Mandating disclosure reduces a firm's expected gain in market share from learning and disclosing impacts. Second, investors' valuation of a firm drops upon disclosure that impacts are high. Therefore, to the extent that a manager is concerned about that valuation, a mandate for disclosure will cause her not to learn about impacts, lest she learn and be forced to disclose that they are high.

"*I don't want to touch it [IPE database of environmental violations by factories in China] or I would not be able to say 'sorry, I don't know'.*" - Sourcing Manager for a major brand, speaking to Ma Jun, Director, Institute for Public Economics

1. Introduction

Hoping to use transparency to motivate firms to reduce the social and environmental impacts associated with their products, governments have started to mandate disclosure of those impacts. This paper shows that these well-intentioned disclosure requirements may instead lead to higher social and environmental impacts.

Learning about the social and environmental impacts associated with a product is difficult and costly, because it requires scrutiny of the extended supply chain- from mining of raw materials, through multiple stages of manufacturing, to final use and disposal. Consider the example of greenhouse gas emissions. Far upstream, the manufacturing of basic materials (chemicals, metals, minerals, paper and petroleum products) accounts for approximately 85% of all industrial energy use and associated CO_2 emissions (IPCC 2007). On average across all industries, a company's direct greenhouse gas (GHG) emissions account for only 14% of emissions from its supply chain (excluding final use, recycling and disposal) (Matthews et al. 2008). For products such as consumer electronics, clothing and automobiles, emissions during final use dominate the other supply chain emissions. As a second example, "conflict minerals" (gold, tantalum, tin and tungsten that are mined and, directly or indirectly, finance armed groups in the Democratic Republic of Congo and nearby) enter far upstream in the complex supply chains for a wide variety of end products, including consumer electronics and automobiles (A.T.Kearney 2012). The worst labor abuses also tend to occur far upstream in the supply chain, though some first-tier suppliers are culpable (Economist 2012). A firm typically knows only its first-tier suppliers. Identifying its upstream suppliers requires effort. Measuring their impacts is challenging because the firm may account for only a small fraction of the supplier's business and lacks a direct sourcing relationship. Consumer behavior and the associated impacts in end use and disposal of a product may be similarly difficult to measure.

A firm that makes the effort to learn about social and environmental impacts in its supply chain will see opportunities to reduce those impacts, profitably or at least at no additional cost. Only a small minority of firms (less than one-third according to the survey by Lee et al. 2012) monitor environmental and social responsibility in their extended supply chains. However, at Walmart (the largest corporation in the world in terms of revenue), a manager describing the company's recent effort to measure and reduce environmental impacts observed that "We had to look at the entire value chain. If we had focused on just our own operations, we would have limited ourselves to 10 % of our effect on the environment and, quite frankly, eliminated 90 % of the opportunity that's out there." By "opportunity", he was referring to the potential to profitably reduce pollution (Plambeck and Denend 2007). Reducing pollution is often coincident with improving productivity, so reducing pollution need not be costly (Porter and van der Linde 1994).

In our model, a firm faces the possibility that in future, it may incur costs associated with its supply chain social and environmental impacts. Such costs might arise due to future climate change policy, for example, or negative publicity regarding suppliers' social or environmental impacts. Indeed, among the firms surveyed by Lee et al. (2012), risk of brand damage is the primary motivation for measuring and addressing supply chain social and environmental impacts.

In valuing a firm, strategic investors try to account for potential future costs associated with its supply chain social and environmental impacts (Institutional Investors Group on Climate Change 2010, Griffin et al. 2012, Ioannou and Serafeim 2010). Managers often make decisions that increase investors' current valuation of a firm at the expense of the firm's long-run profitability (Graham et al. 2005) in part because stock options constitute a large component of executive compensation (Frydman and Saks 2005). Therefore, our model assumes that in deciding whether or not to learn about and disclose impacts, a manager maximizes a weighted sum of the firm's expected discounted profit and its valuation by investors. That objective function is the same as in Bebchuk and Stole (1993) and Schmidt et al. (2011).

An ecolabel can boost a firm's market share, though it typically does not enable a firm to charge a higher price (RESOLVE 2012; Nielsen 2011; Haanaes et al. 2012; Laroche et al. 2001). Voluntary disclosure even of negative social and environmental impact information might increase a firm's market share. For example, Patagonia posted descriptions on its website of the poor working conditions in suppliers' factories and, in a full page advertisement in the New York Times, stated that "the environmental cost of everything we make is astonishing" and disclosed CO_2, water, and waste impacts of its bestselling jacket. Patagonia's sales rose 30 % after that advertisement (Keown 2012). In other contexts, voluntary disclosure of negative information has been shown to increase trust (Hoffman-Graff 1977, Peters et al. 1997) which leads to increased market share (Chaudhuri and Holbrook 2001). We use consumer choice experiments to develop a model of how disclosure of social and environmental impacts affects a firm's market share, depending on whether the disclosed information is positive or negative, and on whether the disclosure is voluntary or mandatory.

Governments are beginning to mandate that firms disclose social and environmental impacts associated with their products. The caveat is that government cannot compel a firm to *know* all the social and environmental impacts of its supply chain, and is therefore limited to requiring that a firm disclose whatever it does know. For example, the U.S. Dodd-Frank Wall Street Reform and Consumer Protection Act mandates that firms must disclose their use of conflict minerals but, following complaints from the National Association of Manufacturers and others regarding the costs and difficulties of learning about conflict minerals in complex supply chains, the Securities and Exchange Commission has granted that a firm may state that whether or not its product contains conflict minerals is "undeterminable" (SEC 2012). In France, a new law grants consumers the right to information about the environmental impact of consumer products. In 2012, a subset of firms will label consumer products with their supply chain greenhouse gas emissions and, if this experiment goes well, the French government will mandate such labels on all consumer products. If a firm has not measured the supply chain emissions associated with its product, it will nevertheless be required to label the product with its best estimate of emissions, likely based on an industry average (French Ministry of Ecology, Sust. Dev. and Energy 2012). Legal scholars Fung et al. (2007) warn that such policies, which require a firm to disclose what it knows, may fail to motivate the firm to take action. Appendix 2 in (Ioannou and Serafeim 2011) provides a list of various countries' mandatory disclosure requirements regarding social, environmental and governance issues.

An extensive empirical literature (much of it based on U.S. Toxic Release Inventory data) suggests that requiring a firm to disclose its emissions will motivate the firm to reduce those emissions; Doshi, Dowell and Toffel (2012) provide an excellent survey. Those papers address a requirement for a firm to disclose information about its *own* emissions, which presumably it knows or can easily learn, while our primary focus in this paper is on supply chain impacts - wherein the issue of learning takes primacy.

The model-based literature (surveyed in Verrecchia 2001) suggests that mandatory disclosure requirements may be unnecessary to elicit full information disclosure by firms but can, paradoxically, increase social welfare by preventing firms from learning and disclosing information. In (Grossman 1981, Milgrom 1981), a seller with private information about the quality of its product always voluntarily discloses that information to customers, because lack of disclosure would be interpreted as a signal of poor quality. Subsequent works, however, show that a firm might choose not to voluntarily disclose information because doing so would be costly, or because customers or investors are uncertain about what the firm knows (Verrecchia 2001). If product quality testing is free, mandating disclosure prevents a seller from testing and (if income and quality are complements) strictly increases expected customer utility and the seller's profit (Matthews and Postlewaite 1985). In Shavell (1994), a seller has private information about the cost it must incur to learn about the quality of its product. Based on whatever information the seller discloses about product quality, a customer undertakes a complementary investment, which ideally would increase with the quality of the product. Without a disclosure requirement, the seller spends more to learn about quality than would be socially optimal, and then withholds negative information, which is inefficient. A mandatory disclosure requirement reduces learning and strictly increases welfare. Our model is similar to Shavell (1994) in that a firm has private information about the cost it must incur to learn about its social and environmental impacts. Unlike that of Shavell, our model incorporates the responses of investors and of consumers to impact information, two different mechanisms by which a mandate for impact disclosure reduces learning.

Consistent with all the theoretical papers cited in the previous paragraph, our model assumes that a firm does not intentionally disclose false information. This is motivated by the fact that in many countries, managers are subject to criminal prosecution for providing false information to investors (Sarbanes-Oxley Act 2002, Zacharias 2010). Moreover, the U.S. Federal Trade Commission is increasingly active in preventing firms from misrepresenting their products' environmental impacts to consumers (Nelson 2010, FTC 2012).

2. Model Formulation

Managers of two competing consumer-goods firms simultaneously decide whether to learn about the social and environmental impacts in their respective supply chains. The cost of learning is a random variable C_i for each firm $i = 1, 2$; these are i.i.d. with continuous distribution $f(\cdot)$ and support $[\underline{c}, \overline{c}]$. The manager of each firm i knows its cost of learning $C_i = c_i$, but knows only the distribution of the other firm's cost of learning. Let G_i denote the level of social and environmental impact in firm i's supply chain impact. (G is mnemonic for greenhouse gas emissions.) Prior to learning, the managers know that the G_i are i.i.d. for $i = 1, 2$; each G_i is at a low level $L \geq 0$ with probability $q \in (0, 1)$ and at a high level $H > L$ with probability $1 - q$. If the manager of firm i chooses to incur the cost c_i she observes the level of impact $G_i = g_i \in \{L, H\}$ and also sees how to reduce those impacts to $G_i = \theta g_i$ at net zero additional cost, where $\theta \in (0, 1)$.

We consider a "mandatory disclosure" scenario in which each manager must reveal whatever she learns, and a "voluntary disclosure" scenario in which, after learning, managers simultaneously decide whether or not to reveal what they have learned. Information disclosure shifts the market share of Firm 1 from $\frac{1}{2}$ to $\frac{1}{2}$ $+\Delta^s_{d_1 d_2}$ where $s \in \{m, v\}$ indicates whether the disclosure was mandatory or voluntary, and $d_i \in \{L, H, \emptyset\}$ indicates that the disclosed level of impact is low θL or high θH, or that the manager did not disclose impact information for firm i, for $i = 1, 2$.

After the managers' disclosure decisions, Firm 1 earns profit at rate $(\frac{1}{2} + \Delta^s_{d_1 d_2})\pi$ and Firm 2 earns profit at rate $(\frac{1}{2} - \Delta^s_{d_1 d_2})\pi$ where $\pi > 0$ denotes the product of the market size and each firm's contribution margin, until an event occurs that causes the firms to incur a cost associated with their impacts. The time until that event occurs is an independent exponential random variable with rate $\lambda > 0$. Therefore, the expected discounted profit of firm i is

$$\Pi_i = \int_0^\infty \lambda e^{-\lambda t}\Big(\int_0^t e^{-\delta x}(\frac{1}{2} \pm \Delta^s_{d_1 d_2})\pi dx + e^{-\delta t}\Omega_i(G_i)\Big) dt, \tag{1}$$

wherein $\Omega_i(G_i)$ denotes its ongoing expected discounted profit, $\delta > 0$ is the discount rate, and the market share $\Delta^s_{d_1 d_2}$ is added for Firm i=1 versus subtracted for Firm i=2. We assume that $\Omega_i(G_i)$ decreases with G_i, the level of impacts at the time that the firm starts to incur a cost associated with impacts. We also assume that initially, a firm that learns that its impact is high has a lower expected ongoing discounted profit than a firm that does not learn:

$$\Omega_i(\theta H) \leq \nu \doteq q\Omega_i(L) + (1-q)\Omega_i(H);$$

that is equivalent to assuming that the reduction in impacts from learning is not too great.

In deciding whether or not to learn, the manager of firm i maximizes:

$$-c + \alpha E_I[\Pi_i | d_1 d_2] + (1-\alpha)\Pi_i \tag{2}$$

where $\alpha \in [0,1]$ and $E_I[\Pi_i|d_1 d_2]$ represent investors' expectation of the discounted profit of firm i contingent on disclosures d_1 and d_2. Specifically, if $d_i \in \{L, H\}$, investors know that firm i has learned and reduced its impacts to $G_i = \theta d_i$, so $E_I[\Pi_i|d_1 d_2]$ is obtained by substituting θd_i for G_i in (**??**). In the mandatory disclosure scenario, if $d_i = \emptyset$, then investors know that firm i did not learn and so $E_I[\Pi_i|d_1 d_2]$ is obtained by substituting $\nu \doteq q\Omega_i(L) + (1-q)\Omega_i(H)$ for $\Omega_i(G_i)$ in (**??**). In the voluntary disclosure scenario, if $d_i = \emptyset$, investors know that either the firm did not learn, or it learned but did not disclose. Hence $E_I[\Pi_i|d_1 d_2]$ is obtained by substituting $E_I[\Omega_i(G_i)\,|d_i = \emptyset]$ for $\Omega_i(G_i)$ in (**??**). Investors are strategic: they evaluate $E_I[\Omega_i(G_i)\,|d_i = \emptyset]$ according to Bayes' rule, using the distribution $f(\cdot)$ for the cost of learning, and the manager's equilibrium strategy for learning and disclosure.

Motivated by the experimental results reported in Section **??**, we assume that when Firm 1 discloses a low impact and Firm 2 does not disclose, Firm 1 gains market share

$$\Delta^v_{L\emptyset} \geq \Delta^m_{L\emptyset} \geq 0. \tag{3}$$

In contrast, when Firm 1 discloses a high impact and Firm 2 does not disclose, Firm 1 gains market share in the voluntary disclosure scenario but loses market share in the mandatory disclosure scenario

$$\Delta^v_{H\emptyset} \geq 0 \geq \Delta^m_{H\emptyset}. \tag{4}$$

When Firm 1 discloses a low impact and Firm 2 discloses a high impact, Firm 1 gains market share in both scenarios

$$\Delta^v_{LH} \geq 0 \text{ and } \Delta^m_{LH} \geq 0. \tag{5}$$

The increase in market share from disclosing low impact is higher when firm 2 discloses high impact

$$\Delta^v_{LH} \geq \Delta^v_{L\emptyset}. \tag{6}$$

Finally, we assume that the shift in market share is symmetric in the firms' disclosures.

Our model formulation is also relevant for some firms with industrial customers. Walmart, for example, considers transparency and environmental performance in allocating its business between competing suppliers; it prefers to purchase more units, rather than pay a higher price per unit, to motivate a supplier to measure, improve and disclose environmental performance. This is consistent with our model formulation in which a firm may gain market share, but not a higher price, by disclosing impact information to a customer. It also suggests that (**??**)-(**??**) hold with strict inequality for a supplier to Walmart.

3. Experimental Results

This section describes the two sets of consumer choice experiments that motivate our modeling assumptions in (??), (??), (??) and (??). These experiments were performed online, with participants drawn from the U.S. national pool administered by Survey Sampling International. To each participant, we presented the pictures, prices, and technical specifications for a laptop from HP (Firm 1) and a similar one from Dell (Firm 2). For different participants, we presented different scenarios regarding the firms' disclosures of environmental or social impacts. We then asked each participant to choose the laptop that he or she would prefer to purchase and to rate how much they trust each firm. Section 3.1 describes the scenarios and results with disclosure of greenhouse gas emissions. Section 3.2 describes the scenarios and results with disclosure of conflict minerals. The Online Appendix reproduces the full surveys.

3.1 Greenhouse Gas Emissions

We used six scenarios with disclosure of greenhouse gas (GHG) emissions, plus a control scenario with no disclosure. In Table **??**, the first three columns identify the scenario. The level of emissions associated with a firm's laptop could be "high" (1263 lbs of CO_2 equivalent) or "low" (754 lbs of CO_2 equivalent); in all but the control scenario, we informed participants that the industry average lifecycle GHG emissions for a laptop computer is approximately 903.9 lbs of CO_2 equivalent. In a voluntary disclosure scenario, a firm could choose not to disclose emission information, which is indicated by "$\emptyset$". In a mandatory disclosure scenario, participants were told that a new U.S. law required a firm to disclose its best estimate of the total lifecycle GHG emissions associated with its product, and "$\emptyset$" indicates that the firm reported only the industry average of 903.9 lbs of CO_2 equivalent.

Scenario			**Percentage Choosing**		**p-value**	**Total**	**Firm 1's Gain In Market Share**
Disclosure	**GHG Emissions**						
	Firm 1	**Firm 2**	**Firm 1**	**Firm 2**			
Control			49.9	50.1		349	
Voluntary	High	$\emptyset$	60.8	39.2	0.002**	352	$\Delta^v_{H\emptyset} > 0$
	Low	$\emptyset$	66.4	33.6	0.000**	354	$\Delta^v_{L\emptyset} > 0$
	Low	High	66.9	33.1	0.000**	350	$\Delta^v_{LH} > 0$
Mandatory	High	$\emptyset$	42.9	57.1	0.033**	354	$\Delta^m_{H\emptyset} < 0$
	Low	$\emptyset$	61.8	38.2	0.003**	352	$\Delta^m_{L\emptyset} > 0$
	Low	High	72.9	27.1	0.000**	351	$\Delta^m_{LH} > 0$

Table 1 **Scenarios regarding disclosure of GHG emissions and the resulting choice of laptop**

Table **??** shows results regarding participants' choice of laptop. Columns five and six show each firm's "market share" (percentage of participants that chose its laptop) under each scenario. Column six reports the p-values from a one-sided proportion test against the control, wherein

** indicates statistical significance at the 0.01 level. Column seven reports the total number of participants that completed the survey under each scenario. Column eight reports whether firm 1 gained ($\Delta > 0$) or lost ($\Delta < 0$) market share relative to the control. When one firm disclosed positive impact information - a low level of emissions - it won greater market share than in the control scenario with no disclosure by either firm (regardless of whether disclosure was voluntary or mandatory and regardless of whether the competitor disclosed a high level of emissions or no emission information for its product). When one firm voluntarily disclosed negative impact information - a high level of emissions- and the competitor did not disclose, the disclosing firm won greater market share than in the control scenario with no disclosure. In contrast, in the mandatory scenario, when one firm disclosed a high level of emissions it lost market share.

Those choice results may be explained by participants' relative levels of trust in the two firms. In Table **??**, columns four and five report the mean and (in parenthesis) the standard deviation of participants' ratings of how much they trust each firm, on a scale from 1 to 10. Column six reports the p-values from a two-sided Wilcoxon ranked-sum test between the ratings for firm 1 and firm 2, wherein ** represents significance at the 0.01 level. With no disclosure, the two firms were statistically indistinguishable in participants' ratings of trust. When one firm disclosed positive impact information - a low level of emissions - it received statistically higher ratings for trust than did the other firm (regardless of whether disclosure was voluntary or mandatory and regardless of whether the competitor disclosed a high level of emissions or no emission information for its product). When one firm voluntarily disclosed negative impact information - a high level of emissions- it received statistically higher ratings for trust than did a competitor that failed to disclose impact information. In contrast, in the mandatory scenario, when one firm disclosed a high level of emissions, it did not receive statistically higher ratings for trust than its competitor.

3.2 Conflict Materials

We used six scenarios with disclosure regarding conflict minerals, plus the control scenario with no disclosure. In Table **??**, the first three columns identify the scenario. "Yes" indicates that a firm disclosed that its product contained conflict minerals. "No" indicates that a firm disclosed that its product was free of conflict minerals. In a voluntary disclosure scenario, a firm could choose not to disclose information about conflict minerals, which is indicated by "$\emptyset$". In a mandatory disclosure scenario, participants were informed that a new U.S. law mandates that a firm must disclose any known use of conflict minerals, and "$\emptyset$" indicates that a firm stated that it has not yet been able to determine that its product is free of conflict minerals.

Table **??** shows results regarding participants' choice of laptop. Column six reports the p-values from a one-sided proportion test against Control, wherein * and ** indicate significance at the

Scenario			Trust Rating		p-value
Disclosure	GHG Emissions				
	Firm 1	Firm 2	Firm 1	Firm 2	
Control			6.993 (1.823)	6.807 (1.933)	0.276
Voluntary	High	∅	6.798 (1.921)	6.327 (2.082)	0.001**
	Low	∅	6.886 (1.875)	6.446 (1.909)	0.000**
	Low	High	6.926 (1.828)	6.431 (2.007)	0.000**
Mandatory	High	∅	6.662 (1.889)	6.673 (1.894)	0.574
	Low	∅	7.145 (1.788)	6.691 (2.091)	0.003**
	Low	High	6.994 (1.724)	6.283 (1.993)	0.000**

Table 2 Scenarios regarding disclosure of GHG emissions and the resulting trust ratings.

Scenario			Percentage Choosing		p-value	Total	Firm 1's Gain In Market Share
Disclosure	Conflict Minerals						
	Firm 1	Firm 2	Firm 1	Firm 2			
Control			49.9	50.1		349	
Voluntary	Yes	∅	49.7	50.3	0.378	348	$\Delta^v_{H\emptyset} = 0$
	No	∅	63.7	36.3	0.000**	344	$\Delta^v_{L\emptyset} > 0$
	No	Yes	70.9	29.1	0.000**	354	$\Delta^v_{LH} > 0$
Mandatory	Yes	∅	43.6	56.4	0.048*	351	$\Delta^m_{H\emptyset} < 0$
	No	∅	65.2	34.8	0.000**	348	$\Delta^m_{L\emptyset} > 0$
	No	Yes	70.0	30.0	0.000**	340	$\Delta^m_{LH} > 0$

Table 3 Scenarios regarding disclosure of conflict minerals and resulting choice of laptop

0.05 and 0.01 levels respectively. The results regarding the sign of Δ are exactly the same as those reported in Table **??** for greenhouse gas emissions, with a single exception: when one firm voluntarily disclosed negative impact information - that its product contains conflict minerals - and the competitor did not disclose impact information, the disclosing firm did not have a statistically significant change in market share relative to the control ($\Delta^v_{H\emptyset} = 0$). However, an additional proportion test shows that that firm disclosing voluntarily did have statistically higher market share than if its disclosure had been mandated: $\Delta^v_{H\emptyset} > \Delta^m_{H\emptyset}$ (*p-value* = 0.06).

Table **??** shows results regarding participants' trust in the firms. Column six reports the p-values from a two-sided Wilcoxon ranked-sum test between the ratings for firm 1 and firm 2, wherein * and ** represent significance at the 0.05 and 0.01 levels, respectively. The results are qualitatively the same as in Table **??** for greenhouse gas emissions. Most interestingly, when one firm voluntarily disclosed negative impact information - conflict minerals in its product- it received statistically higher ratings for trust than did a competitor that failed to disclose impact information.

Scenario			**Trust Rating**		**p-value**
Disclosure	**Conflict Minerals**				
	Firm 1	**Firm 2**	**Firm 1**	**Firm 2**	
Control			6.993 (1.823)	6.807 (1.933)	0.276
Voluntary	Yes	$\emptyset$	6.552 (1.776)	6.218 (1.956)	0.046*
	No	$\emptyset$	6.846 (1.904)	6.195 (1.972)	0.000**
	No	Yes	6.898 (1.804)	6.410 (1.896)	0.000**
Mandatory	Yes	$\emptyset$	6.778 (1.760)	6.584 (1.817)	0.215
	No	$\emptyset$	6.839 (1.821)	6.362 (2.013)	0.001**
	No	Yes	6.844 (1.871)	6.306 (1.934)	0.000**

Table 4 Scenarios regarding disclosure of Conflict Minerals and resulting rating of trust.

4. Analytical Results

Our first result is that a mandate may not be necessary to elicit full information disclosure.

PROPOSITION 1. *An equilibrium exists in which both firms voluntarily disclose all information that they learn about social and environmental impacts, if and only if $\alpha \leq \overline{\alpha}$. The threshold $\overline{\alpha}$ is strictly positive only if $\Delta^v_{H\emptyset} > 0$ and it decreases with $|\Delta^v_{HL}|$.*

A manager who learns that impacts are low will voluntarily disclose that information, because it will boost both sales and investors' valuation of the firm. A manager who learns that impacts are high might voluntarily disclose that information because $\Delta^v_{H\emptyset} > 0$, meaning that a firm will gain market share from disclosing a high impact if the competitor does not disclose impact information. The trade-off is that, to the extent that $|\Delta^v_{HL}|$ is large, the firm will lose market share from disclosing a high impact if the competitor discloses a low impact, and disclosing a high impact will reduce investors' valuation of the firm. Hence a manager discloses high impact only if she places little weight on that valuation, α is small, and $|\Delta^v_{HL}|$ also is small. Proposition 1 is consistent with our motivating example of voluntary disclosure by Patagonia, for which $\alpha = 0$ because the firm has a single owner/founder who remains involved in management and $\Delta^v_{H\emptyset} > 0$ according to (Keown 2012).

Our main result is that mandating disclosure has the opposite effect of the one intended by policy makers.

THEOREM 1. *Mandating that firms disclose their social and environmental impact information **increases** those impacts.*

The rationale is that the mandate deters managers from learning and thus reducing impacts in their supply chains. The loss of learning occurs for two different reasons. The first is customer choice. In our experiments, inequalities in (**??**)-(**??**) hold, and at least one is satisfied strictly ($\Delta^m_{H\emptyset} < 0$ for all experimental scenarios and $\Delta^v_{H\emptyset} > 0$ in the scenario where firms can disclose GHG emissions). Therefore, mandating disclosure strictly reduces a firm's expected increase in market share from learning- regardless of whether the firm's impact is high or low, and regardless of whether or not the firm's manager would voluntarily disclose a high impact as in Proposition 1. The second reason arises if the manager would not voluntarily disclose a high impact, because doing so would reduce the firm's expected market share and/or valuation by investors. Then, a mandate for disclosure discourages a manager from learning, to avoid being forced to disclose that impacts are high.

Theorem 1 is very robust, in that any equilibrium in the voluntary disclosure scenario involves more learning and impact reduction than any equilibrium in the mandatory disclosure scenario. Its proof allows for equilibria in mixed strategies.

For the remainder of this section, we impose the following additional modeling assumptions. First, we assume a constant marginal future cost associated with impacts:

$$\Omega_i'(G_i) = -\tau \tag{7}$$

where $\tau > 0$ might be interpreted, for example, as the expected cost of carbon under a future climate policy. We define the average impact before learning as

$$\mu \doteq qL + (1-q)H.$$

Second, in the scenario with voluntary disclosure, we assume that the two managers follow a symmetric pure strategy equilibrium. That could involve full disclosure (in the parameter region identified in Proposition 1) or partial disclosure, i.e., disclosure only upon learning that impacts are low. We assume that the support of the cost of learning is $[0, \infty)$. Universally, a manager's best response is to learn if and only if the cost of learning is below a threshold. If a symmetric partial disclosure equilibrium exists, it is characterized by a unique threshold for learning; a sufficient condition for this to be true is that $f(c)/(1 - F(c)q)$ increases with c.

Proposition 2 shows that a manager's concern regarding investors' valuation of the firm exacerbates the negative effect of mandating disclosure.

Proposition 2. *Suppose that $\alpha > \overline{\alpha}$, meaning that no manager will voluntarily disclose a high level of impacts. The increase in impacts caused by mandating disclosure increases with α.*

The proof shows that in an equilibrium with partial voluntary disclosure, the maximum cost at which a manager chooses to learn increases with α. Because the manager will choose only to disclose a low impact, which will increase investors' valuation of the firm, as the manager's concern about that valuation, α, increases, the manager becomes more motivated to learn. In contrast, under mandatory disclosure, the maximum cost at which a manager chooses to learn is invariant with respect to α.

In the consumer choice experiments reported in Section **??**, we observed that at least one of the inequalities in (4) is strict: Mandatory disclosure of high impact strictly reduces a firm's market share, whereas voluntary disclosure of high impact may strictly increase a firm's market share, if the competitor does not disclose. Proposition 3 shows that this exacerbates the negative effect of mandating disclosure.

Proposition 3. *Accounting for consumers' response to disclosure of a high impact (making either of the inequalities in (**??**) strict, as opposed to assuming that $\Delta^v_{H\emptyset} = \Delta^m_{H\emptyset}$) increases the increase in impacts caused by mandating disclosure.*

Despite the negative result in Theorem 1, some stakeholders may lobby for government to mandate disclosure. Propositions 4 and 5 identify conditions under which investors and managers will do so. Following Gibbons (1992), Schmidt et al. (2011) and references therein, let us assume that investors dislike divergence between their expectation of a firm's discounted profit (based on what the firm does or does not disclose) and the firm's actual discounted profit, so that the utility function for investors is $-E[(\Pi_1 - E_I[\Pi_1])^2]$.

Proposition 4. *Suppose that $\alpha > \overline{\alpha}$, meaning that no manager will voluntarily disclose a high level of impacts. A mandate to disclose social and environmental impact increases investors' utility if and only if $\alpha \leq \hat{\alpha}$. Accounting for consumers' response to disclosure of a high impact (making either of the inequalities in (**??**) strict, as opposed to assuming that $\Delta^v_{H\emptyset} = \Delta^m_{H\emptyset}$) decreases the threshold $\hat{\alpha}$.*

Investors should lobby for mandatory disclosure when a manager will not voluntarily disclose a high impact level, but is not too concerned about investors' valuation of the firm. The rationale is that, as explained after Proposition 2, when a manager will voluntarily choose to disclose only a low impact, learning increases with α, which benefits investors, and causes investors to prefer voluntary to mandatory disclosure when α is sufficiently high. Consumers' response to disclosure of a high impact also tends to make investors better off under voluntary than mandatory disclosure, by motivating relatively more learning in the scenario with voluntary disclosure.

A manager that faces a very high cost of learning about social and environmental impacts should lobby for mandatory disclosure.

Proposition 5. *Suppose that a firm's cost of learning c is sufficiently high to prevent it from learning in the scenario with voluntary disclosure. A mandate for disclosure will increase the firm's expected profit and valuation.*

The first reason is that a manager with a high cost of learning will not invest in learning, and therefore stands to lose market share in the event that a competitor learns and discloses impact information. The mandate for disclosure will mitigate her expected loss in market share. The second reason is that a mandate for disclosure increases investors' valuation of a firm that does not disclose. The mandate for disclosure enables investors to infer that the firm has a high cost of learning that prevented it from learning. Without the mandate, investors think that the firm may have chosen not to disclose because its impacts are high, and increase their expectation of the firm's impacts and associated future costs, accordingly.

Regardless of whether disclosure is mandatory or voluntary, when a manager anticipates a higher cost associated with social and environmental impacts τ, she will invest more in learning and thus in reducing those impacts. Investors benefit from that learning and associated increase in disclosure. More surprisingly, in the scenario with mandatory disclosure, an increase in the cost τ can benefit the firms. It counteracts the problem that a manager underinvests in learning (especially when α is high) to avoid being forced to reveal to investors that impacts are high.

Proposition 6. *Increasing the expected cost per unit impact τ in (**??**) reduces impacts and increases investors' utility. It can increase a firm's expected discounted profit and valuation under mandatory disclosure.*

5. Concluding Remarks

Suppose that a firm invests in learning and finds out that impacts are worse than it anticipated. Should it nevertheless disclose them? The answer is "yes" in the case of GHG emissions, but "no" in the case of conflict minerals. Recall from Section 3.1 that a firm that voluntarily discloses a very high level of GHG emissions gains market share if the competitor does not disclose information about GHG emissions: $\Delta^v_{H\emptyset} > 0$. If the competitor were to subsequently respond by disclosing a similarly high level of emissions, the firm would be no worse off. Additional experiments suggest that if the competitor were to subsequently respond by disclosing a low level of emissions, the firm could prevent a loss of market share by reminding consumers of its leadership in disclosure and providing detailed information about its emissions and reduction efforts (details are given in Appendix B). The marketing literature on "brand loyalty" and "usage dominance" implies that an initial gain in market share (for a firm that is first to disclose) will generate a persistent market share advantage (Guadagni and Little 1983, Deighton et al. 1994, Villas-Boas 2004). We therefore recommend that a firm should voluntarily disclose even a high level of greenhouse gas emissions.

Regarding conflict minerals, we observed that a firm that voluntarily discloses that its product contains conflict minerals neither gains nor loses market share, if the competitor does not disclose information about conflict minerals: $\Delta^v_{H\emptyset} = 0$. However, it loses market share if the competitor discloses that its product is free of conflict minerals ($\Delta^v_{LH} > \Delta^v_{L\emptyset}$). We therefore recommend that a firm should not voluntarily disclose that its product contains conflict minerals.

Policy makers and NGOs should recognize and act upon the fundamental tenet of operations management that *measurement leads to improvement*. Some governments are starting to require a firm to disclose what it knows regarding greenhouse gas emissions or conflict minerals in its supply chain. Our main result is that such a requirement will deter measurement. To promote measurement, policy makers could potentially require firms to measure their supply chain impacts in a specific manner, and obtain third party certification that they are doing so; indeed, activists have called for such requirements regarding conflict minerals (Dunneback 2012). However, firms have convinced the regulatory authorities that specific learning requirements and third party verification thereof would be prohibitively costly and difficult to implement, because they have numerous suppliers spanning several tiers that are constantly being changed (National Association of Manufacturers 2012, SEC 2012). As an alternative approach to promote measurement, policy makers could facilitate firms' efforts to measure their suppliers' impacts. Commonly in emerging economies, suppliers bribe auditors and local officials, falsify documents, and coach employees in how to corroborate those false documents, in order to "pass" audits. To the extent that government authorities penalize such corruption and deception, buyers will undertake more auditing, auditing will be more effective in measuring impacts, and suppliers will exert more effort to reduce their impacts (Plambeck et al. 2012).

Our model suggests three ways in which NGOs can spur firms to measure and reduce their supply chain impacts. First, NGOs can reduce a firm's cost of doing so. Walmart's recent success in profitable environmental impact reduction has been accomplished through partnership with environmental NGOs that give the firm unprecedented visibility of its extended supply chain (Plambeck and Denend 2007). The Institute for Public Economics (IPE) maintains an internet database of environmental violations by factories in China, which enables a firm to easily identify violations by its suppliers. Second, NGOs can expose and publicly shame firms for abuses in their supply chains. For example, the IPE assiduously collects evidence that prominent multinational firms are sourcing from offending factories in its database. Only by threatening to widely publicize such abuses (which translates into increasing τ in our model) can IPE motivate many firms to use its database and demand improvement from suppliers (Ma 2012). Third, NGOs - and educators- can sensitize people to issues like conflict minerals and climate change, which may magnify a firm's gain in market share from voluntarily disclosing its impacts, magnify a firm's loss in market share in the event that abuses in its supply chain are exposed, and thus spur firms to measurement and improvement.

References

A.T.Kearney. 2012. Conflict Minerals: Yet Another Supply Chain Challenge. Retrieved October 12, 2012, http://www.atkearney.com.

Bebchuk, L.A., L.A. Stole. 1993. Do Short-term Objectives lead to Under- or Overinvestment in Long-term projects? *The Journal of Finance*. 18(2), 719-729.

Chaudhuri, A., M.B. Holbrook. 2001. The Chain of Effects from Brand Trust and Brand Affect to Brand Performance: The Role of Brand Loyalty. *Journal of Marketing*. 65(2), 81-93.

Deighton, J., C.M. Henderson, S.A. Neslin. 1994. The Effects of Advertising on Brand Switching and Repeat Purchasing. *Journal of Marketing Research.* 31(1), 28-43.

Doshi, A., G. Dowell, M.W. Toffel. 2012. How Firms Respond to Mandatory Information Disclosure. Working Paper, Harvard Business School.

Dunnebacke, A. 2012. Anti-Corruption Views - Global Witness Comments on SEC Conflict Minerals Rule. Retrieved Nov 10, 2012, http://www.trust.org/trustlaw/blogs/anti-corruption-views/global-witness-comments-on-sec-conflict-minerals-rule/.

Economist. 2012. When the Job Inspector Calls: Do Campaigns for "Ethical Supply Chains" help workers?". *Economist*, 31 March. Available at: http://www.economist.com/node/21551498.

Frydman, C., R.E. Saks. 2005. Executive Compensation: A New View from a Long-Term Perspective, 1936-2005. *The Review of Financial Studies*. 23(5), 2109-2138.

Fung, A., M. Graham, D. Weil. 2007. *Full Disclosure: The Perils and Promise of Transparency.* Cambridge University Press, New York, NY 48-49.

Gibbons, M.R., 1982. Multivariate Tests of Financial Models: A new approach. *Journal of Financial Economics*. 10(1), 3-27.

Graham, J.R., Harvey, C.R., Rajgopal, S., 2005. The Economic Implications of Corporate Financial Reporting. *Journal of Accounting and Economics*. 40(1), 3-73.

Grossman, S.J.,1981. The Role of Warranties and Private Disclosure about Product Quality. *Journal of Law and Economics*. 24, 461-483.

Griffin, P.A., D.H. Lont, Y. Sun. 2012. Supply Chain Sustainability: Evidence on Conflict Minerals. Working Paper. Available at SSRN: http://ssrn.com/abstract=2129371.

Guadagni, P.M., J. Little. 1983. A Logit Model of Brand Choice Calibrated on Scanner Data. *Marketing Science.* 2(3), 203-238.

Haanaes, K., R. Martin, I.Velken, M. Audretsch, D. Kiron, N. Kruschwitz. 2012. Findings from the 2011 Sustainability & Innovation Global Executive Study and Research Project: Sustainability Nears a Tipping Point. *MIT Sloan Management Review Research Report.* Winter 2012.

Hoffman-Graff, M.A.1977. Interviewer Use of Positive and Negative Self-Disclosure and Interviewer-Subject Sex Pairing. *Journal of Counseling Psychology.* 24(3), 184-190.

Institutional Investors Group on Climate Change. 2010. Global Investor Survey on Climate Change: Annual Report on Actions and Progress 2010. Retrieved October 7, 2012, http://www.iigcc.org__data/assets/pdf_file/0014/15224/Global-Investor-Survey-on-Climate-Change-Report-2011.pdf.

Ioannou, I., G. Serafeim. 2010. The Impact of Corporate Social Responsibility on Investment Recommendations. Harvard Business School Working Paper No. 1507874. Available at SSRN: http://ssrn.com/abstract=1507874 or http://dx.doi.org/10.2139/ssrn.1507874.

Ioannou, I., G. Serafeim. 2011. Consequences of Mandatory Corporate Sustainability Reporting. Harvard Business School Research Working Paper No. 11-100. Available at SSRN: http://ssrn.com/abstract=1799589 or http://dx.doi.org/10.2139/ssrn.1799589.

IPCC. 2007. Contribution of Working Group III to the Fourth Assessment Report of the Intergov- ernmental Panel on Climate Change, B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds) Cambridge University Press, Cambridge, UK and New York, NY, USA.

Keown, J., 2012. Boosts sales by saying ‘don't buy’. In Stuff.co.nz. Retrieved August 2, 2012, http://www.stuff.co.nz/business/industries/6656053/Boosts-sales-by-saying-don-t-buy.

Laroche, M., J. Bergeron, G. Barbaro-Forleo. 2001. *Journal of Consumer Marketing.* 18, 503-520.

Lee, H.L., K. O'Marah., G. John. 2012. The Chief Supply Chain Officer Report 2012. *SCM World*.

Ma, J. 2012. Author's Interview of Ma Jun, Director of the Institute for Public Economics, October 12, 2012.

Matthews, H.S., C.T. Hendrickson, C.L. Weber. 2008. The Importance of Carbon Footprint Estimation Boundaries. *Environmental Science and Technology.* 42, 5839-5842.

Matthews, S., A. Postlewaite. 1985. Quality Testing and Disclosure. *The RAND Journal of Economics.* 16(3), 328-340.

Milgrom, P. 1981. Good News and Bad News: Representation Theorems and Applications. *Bell Journal of Economics.* 12, 380-391.

Ministry of Ecology, Sust. Dev. and Energy (France). 2012. ExpŽrimentation de lÕaffichage environnemental. Retrieved August 2, 2012, http://www.developpement-durable.gouv.fr/National-experimentation-for-the.

National Association of Manufacturers, 2012. Testimony of Franklin Vargo before the House Committee on Financial Services Subcommittee on International Monetary Policy and Trade, p7.

Nelson, G. 2010. FTC Moves May Signal Start of 'Greenwashing' Crackdown. Retrieved August 2, 2012, http://www.nytimes.com/gwire/2010/02/03/03greenwire-ftc-moves-may-signal-start-of-greenwashing-cra-90834.html?pagewanted=all.

Nielsen, 2011. Sustainability Survey: Global Warming Cools Off as Top Concern. Retrieved October 2012, http://www.nielsen.com/us/en/insights/press-room/2011/global-warming-cools-off-as-top-concern.html.

Peters, R.G., V.T. Covello, D.B., McCallum.1997. The Determinants of Trust and Credibility in Environmental Risk Communication: An Empirical Study. *Risk Analysis*. 17(1), 43-54.

Plambeck, E.L., L. Denend. 2007. Walmart's Sustainability Strategy. OIT-71A and B. Stanford Graduate School of Business Case Study. Updated 2010.

Plambeck, E.L., T. Taylor and Q. Zhang. 2012. Supplier Evasion of a Buyer's Audit: Implications for Auditing and Compliance with Labor and Environmental Standards. Working Paper.

Porter, M.E., C. van der Linde. 1995. Toward a New Conception of the Environment-competitiveness Relationship. *The Journal of Economics Perspectives* 9(4), 97-118.

RESOLVE. 2012. Toward Sustainability: The Roles and Limitations of Certification. Washington, DC: RESOLVE, Inc.

Sarbanes-Oxley Act of 2002. Pub. L. 107-204, *United States Statutes at Large*. 116 STAT. 745. July 30, 2002. Section 802(a).

Schmidt, W., V. Gaur, R. Lai, A. Raman. 2012. Signaling to Partially Informed Investors in the Newsvendor Model. Working Paper, Harvard Business School.

Shavell, S.M. 1994. Acquisition and Disclosure of Information Prior to Sale. *RAND Journal of Economics*. 25(1) 20-36.

Securities and Exchange Commission. 2012. SEC Adopts Rule for Disclosing Use of Conflict Minerals. Retrieved August 25, 2012, http://www.sec.gov/news/press/2012/2012-163.htm.

—. Federal Trade Commission, 2012. Skechers Will Pay $40 Million to Settle FTC Charges That It Deceived Consumers with Ads for "Toning Shoes". Retrieved August 2, 2012, http://ftc.gov/opa/2012/05/consumerrefund.shtm.

Villas-Boas, J.M., 2004. Consumer Learning, Brand Loyalty and Competition. *Marketing Science.* 23(1), 134-145.

Verrecchia, R.E., 2001. Essays on Disclosure. *Journal of Accounting and Economics*. 32. 97-180.

Zacharias, C. 2010. Important International Developments in Executive Liability. ACE Progress Reports. Retrieved August 2012, http://www.aceusa.com/news.

Appendix A: Proofs

Assumptions $\Delta^v_{L\emptyset} \geq 0$, $\Delta^v_{H\emptyset} \geq 0$, and $\Delta^v_{LH} \geq 0$ imply that disclosing low impact voluntarily increases a firm's market share. Disclosing low impact also increases its valuation because upon nondisclosure, the investors will estimate that the firm's expected discounted profit after the event is a weighted average of its expected discounted profit under no learning and its expected discounted profit under learning and no disclosure (which is less than or equal to $\Omega(\theta L)$). This estimate is strictly less than or equal to $\Omega(\theta L)$. Therefore, a firm that learns that it has low impact will disclose under voluntary disclosure.

There are two possible equilibria in pure strategies where the firms will disclose low impact: (1) *full disclosure equilibrium* where firms disclose all information (even after learning that impacts are high), (2) *partial disclosure equilibrium* where firms disclose *only* after learning that impacts are low.

Lemma 1. *(i) Under mandatory disclosure, if firm 2 learns its impact with probability p_2, firm 1's expected discounted profit from learning that its impact is low, learning that its impact is high, and not learning are given by the following expressions, respectively:*

$$E_{d_2}[\Pi_1|g_1 = \theta L, d_2] = \frac{\pi(\frac{1}{2} + p_2(1-q)\Delta^m_{LH} + (1-p_2)\Delta^m_{L\emptyset}) + \lambda\Omega(\theta L)}{\delta + \lambda}. \tag{8}$$

$$E_{d_2}[\Pi_1|g_1 = \theta H, d_2] = \frac{\pi(\frac{1}{2} - p_2 q\Delta^m_{LH} + (1-p_2)\Delta^m_{H\emptyset}) + \lambda\Omega(\theta H)}{\delta + \lambda}. \tag{9}$$

$$E_{G_1,d_2}[\Pi_1|g_1, d_2] = \frac{\pi(\frac{1}{2} - p_2 q\Delta^m_{L\emptyset} - p_2(1-q)\Delta^m_{H\emptyset}) + \lambda(q\Omega(L) + (1-q)\Omega(H))}{\delta + \lambda}. \tag{10}$$

(ii) Under full voluntary disclosure, (??), (??), and (??) hold with the substitution of $\Delta^v_{L\emptyset}$, $\Delta^v_{H\emptyset}$, and Δ^v_{LH} for $\Delta^m_{L\emptyset}$, $\Delta^m_{H\emptyset}$, and Δ^m_{LH}.

(iii) Under partial voluntary disclosure, if firm 1 learns its impact with probability p_1 and firm 2 learns its impact with probability p_2, firm 1's expected discounted profit from learning that its impact is low, learning that its impact is high, and not learning are given by the following expressions, respectively:

$$E_{d_2}[\Pi_1|g_1 = \theta L, d_2] = \frac{\pi(\frac{1}{2} + (1-p_2 q)\Delta^v_{L\emptyset}) + \lambda\Omega(\theta L)}{\delta + \lambda}, \tag{11}$$

$$E_{d_2}[\Pi_1|g_1 = \theta H, d_2] = \frac{\pi(\frac{1}{2} - p_2 q\Delta^v_{L\emptyset}) + \lambda\Omega(\theta H)}{\delta + \lambda}, \tag{12}$$

$$E_{G_1,d_2}[\Pi_1|g_1, d_2] = \frac{\pi(\frac{1}{2} - p_2 q\Delta^v_{L\emptyset}) + \lambda(q\Omega(L) + (1-q)\Omega(H))}{\delta + \lambda}. \tag{13}$$

When firm 1 does not disclose, its valuation by the investors is

$$E_{d_2}[E_I[\Pi_1|d_1 = \emptyset, d_2]] = \frac{\pi(\frac{1}{2} - p_2 q\Delta^v_{L\emptyset}) + \lambda\Omega_I}{\delta + \lambda}, \tag{14}$$

where

$$\Omega_I = (p_1(1-q)\Omega(\theta H) + (1-p_1)(q\Omega(L) + (1-q)\Omega(H)))/(1-p_1 q). \tag{15}$$

The proof of Lemma **??**, straightforward algebra, is in the Online Appendix.

LEMMA 2. *A manager chooses to learn if and only if the cost of doing so is below a threshold. The thresholds are identical for both firms.*

(i) Under mandatory disclosure, the threshold is

$$c^m = \frac{\pi(q\Delta^m_{L\emptyset} + (1-q)\Delta^m_{H\emptyset}) + \lambda(q\Omega(\theta L) + (1-q)\Omega(\theta H) - q\Omega(L) - (1-q)\Omega(H))}{\delta + \lambda}. \tag{16}$$

(ii) Under full voluntary disclosure, the threshold is

$$c^v = \frac{\pi(q\Delta^v_{L\emptyset} + (1-q)\Delta^v_{H\emptyset}) + \lambda(q\Omega(\theta L) + (1-q)\Omega(\theta H) - q\Omega(L) - (1-q)\Omega(H))}{\delta + \lambda}. \tag{17}$$

(iii) Under partial voluntary disclosure, the threshold is

$$c^v = \frac{A - q\lambda\alpha\Omega_I}{\delta + \lambda} \tag{18}$$

where

$$A = q\pi\Delta^v_{L\emptyset} + \lambda(q\Omega(\theta L) + (1-q)(1-\alpha)\Omega(\theta H) - (1-\alpha)(q\Omega(L) + (1-q)\Omega(H))) \tag{19}$$

and

$$\Omega_I = \frac{(1-F(c^v))(q\Omega(L) + (1-q)\Omega(H)) + F(c^v)(1-q)\Omega(\theta H)}{1 - F(c^v)q}. \tag{20}$$

Proof of Lemma ??: Given the objective value of a manager in (**??**), if the manager chooses to learn when the learning cost is $\tilde{c}$, he will also choose to do so when the learning cost is less than $\tilde{c}$. This is because the expected discounted profit and valuation after learning are independent of the learning cost. This implies that a manager will choose to learn according to a threshold policy (i.e., he will choose to learn if the learning cost is below a threshold). In the following analysis for voluntary and mandatory disclosure, we identify these thresholds for each firm.

Mandatory Disclosure: We calculate and compare the objective value in (**??**) of firm 1's manager under learning and no learning given that firm 2 uses a threshold policy (i.e., learns if the learning cost is below c_2^m) under mandatory disclosure. Due to mandatory disclosure, valuation of firm 1 equals expected discounted profit. Hence, a manager's objective in (**??**) simplifies to firm 1's expected discounted profit. Manager's objective function under learning equals

$$-c + qE_{d_2}[\Pi_1|g_1 = \theta L, d_2] + (1-q)E_{d_2}[\Pi_1|g_1 = \theta H, d_2]. \tag{21}$$

Here, $E_{d_2}[\Pi_1|g_1 = \theta L, d_2]$ is the firm's expected discounted profit upon finding out low impact, which is calculated by replacing $E[G_1] = \theta L$ in (**??**) and where the expectation is taken with respect to firm 2's disclosure.

Manager's objective function under no learning equals the expected discounted profit of the firm where the expectation is taken with respect to both firm 1's impact and firm 2's disclosure:

$$E_{G_1,d_2}[\Pi_1|g_1, d_2]. \tag{22}$$

The manager will choose to learn if and only if (**??**) is greater than or equal to (**??**). Using closed-form expressions for $E_{d_2}[\Pi_1|g_1=\theta L, d_2]$, $E_{d_2}[\Pi_1|g_1=\theta H, d_2]$, and $E_{G_1,d_2}[\Pi_1|g_1, d_2]$ in Lemma **??** with $p_2 = F(c_2^m)$, expected discounted profit after learning is

$$qE_{d_2}[\Pi_1|g_1=\theta L, d_2] + (1-q)E_{d_2}[\Pi_1|g_1=\theta H, d_2] = \frac{\pi(\frac{1}{2}+(1-F(c_2^m))(q\Delta_{L\emptyset}^m+(1-q)\Delta_{H\emptyset}^m)) + \lambda(q\Omega(\theta L)+(1-q)\Omega(\theta H))}{\delta+\lambda}$$

and expected discounted profit without learning equals

$$E_{G_1,d_2}[\Pi_1|g_1,d_2] = \frac{\pi(\frac{1}{2}-F(c_2^m)(q\Delta_{L\emptyset}^m+(1-q)\Delta_{H\emptyset}^m)) + \lambda(q\Omega(L)+(1-q)\Omega(H))}{\delta+\lambda}.$$

Therefore, the manager will choose to learn if and only if

$$c \le c_1^m = \frac{\pi(q\Delta_{L\emptyset}^m+(1-q)\Delta_{H\emptyset}^m) + \lambda(q\Omega(\theta L)+(1-q)\Omega(\theta H) - q\Omega(L) - (1-q)\Omega(H))}{\delta+\lambda}.$$

Note that the learning threshold for firm 1, c_1^m, is independent of c_2^m. Since the firms are symmetric, $c_1^m = c_2^m = c^m$.

Full voluntary disclosure: This solution of this scenario can be obtained directly from the mandatory disclosure scenario by substituting $\Delta_{L\emptyset}^v$, $\Delta_{H\emptyset}^v$, and Δ_{LH}^v for $\Delta_{L\emptyset}^m$, $\Delta_{H\emptyset}^m$, and Δ_{LH}^m.

Partial voluntary disclosure: Similar to our analysis under mandatory disclosure, we calculate and compare the objective value in (**??**) of firm 1's manager under learning and no learning given that firm 2 uses a threshold policy (i.e., learns if the learning cost is below c_2^v). The manager's objective value (**??**) when she learns is

$$-c+q\Big[\alpha E_{d_2}[E_I[\Pi_1|d_1=L,d_2]]+(1-\alpha)E_{d_2}[\Pi_1|g_1=\theta L,d_2]\Big]+(1-q)\Big[\alpha E_{d_2}[E_I[\Pi_1|d_1=\emptyset,d_2]]+(1-\alpha)E_{d_2}[\Pi_1|g_1=\theta H,d_2]\Big].$$

The first (second) set of terms in brackets is the weighted sum of firm's expected discounted profit and valuation upon finding out it has low (high) impact. Expected discounted profit upon learning that impact is high is $E_{d_2}[\Pi_1|g_1=\theta H, d_2]$. The manager chooses not to disclose high impact, hence $d_1=\emptyset$ and the valuation of the firm is $E_{d_2}[E_I[\Pi_1|d_1=\emptyset, d_2]]$. Since a firm discloses low impact, $E_{d_2}[\Pi_1|g_1=\theta L, d_2] = E_{d_2}[E_I[\Pi_1|d_1 = L, d_2]]$. Therefore, the objective under learning can be rewritten as

$$-c+qE_{d_2}[\Pi_1|g_1=\theta L,d_2]+(1-q)\Big[\alpha E_{d_2}[E_I[\Pi_1|d_1=\emptyset,d_2]]+(1-\alpha)E_{d_2}[\Pi_1|g_1=\theta H,d_2]\Big]. \tag{23}$$

The manager's objective value in (**??**) without learning equals

$$\alpha E_{d_2}[E_I[\Pi_1|d_1=\emptyset,d_2]]+(1-\alpha)E_{G_1,d_2}[\Pi_1|g_1,d_2], \tag{24}$$

wherein the first term is the expected valuation of the firm upon nondisclosure and the outer expectation is taken with respect to firm 2's disclosure. The second term is the expected discounted profit of the firm where the expectation is taken with respect to both firm 1's impact and firm 2's disclosure. The manager will choose to learn if and only if (**??**) is greater than or equal to (**??**).

Using (**??**), (**??**), and (**??**) in Lemma **??** (with $p_2 = F(c_2^v)$), (**??**) simplifies to

$$-c+\frac{\pi(\frac{1}{2}+q(1-F(c_2^v))\Delta_{L\emptyset}^v) + \lambda(q\Omega(\theta L)+(1-q)\alpha\Omega_I+(1-q)(1-\alpha)\Omega(\theta H))}{\delta+\lambda}. \tag{25}$$

Using (**??**) and (**??**) in Lemma **??** (with $p_2 = F(c_2^v)$), (**??**) simplifies to

$$\frac{\pi(\frac{1}{2} - F(c_2^v)q\Delta_{L\emptyset}^v) + \lambda(\alpha\Omega_I + (1-\alpha)(q\Omega(L) + (1-q)\Omega(H)))}{\delta+\lambda}. \tag{26}$$

Taking the difference between (**??**) and (**??**), the manager will choose to learn if and only if

$$c \le c_1^v = \frac{A - q\lambda\alpha\Omega_I}{\delta+\lambda}, \tag{27}$$

$$A = q\pi\Delta_{L\emptyset}^v + \lambda(q\Omega(\theta L) + (1-q)(1-\alpha)\Omega(\theta H) - (1-\alpha)(q\Omega(L) + (1-q)\Omega(H))).$$

Following (**??**) (with $p_1 = F(c_1^v)$), Ω_I satisfies

$$\Omega_I = \frac{(1-F(c_1^v))(q\Omega(L) + (1-q)\Omega(H)) + F(c_1^v)(1-q)\Omega(\theta H)}{1-F(c_1^v)q}. \tag{28}$$

For a partial disclosure equilibrium to occur, there must be a solution (c_1^v, Ω_I) that satisfies (**??**) and (**??**). We now verify that such a solution exists. As $\Omega_I = \frac{A - c_1^v(\delta+\lambda)}{q\lambda\alpha}$, (**??**) can be represented as

$$(1-F(c_1^v)q)\frac{A - c_1^v(\delta+\lambda)}{q\lambda\alpha} = (1-F(c_1^v))(q\Omega(L) + (1-q)\Omega(H)) + F(c_1^v)(1-q)\Omega(\theta H). \tag{29}$$

This can be further simplified to

$$R = (1-F(c_1^v))\Big[(q\Omega(L) + (1-q)\Omega(H)) - \frac{A - c_1^v(\delta+\lambda)}{q\lambda\alpha}\Big] + F(c_1^v)(1-q)\Big[\Omega(\theta H) - \frac{A - c_1^v(\delta+\lambda)}{q\lambda\alpha}\Big] = 0. \tag{30}$$

Ω_I is a weighted average of $(q\Omega(L) + (1-q)\Omega(H))$ and $\Omega(\theta H)$, so it should satisfy $\Omega(\theta H) \le \Omega_I = \frac{A - c_1^v(\delta+\lambda)}{q\lambda\alpha} \le (q\Omega(L) + (1-q)\Omega(H))$. We define c_l to be the cost threshold from (**??**) when $\Omega_I = q\Omega(L) + (1-q)\Omega(H)$ and c_h to be cost threshold from (**??**) when $\Omega_I = \Omega(\theta H)$. If $c_l \le \underline{c}$, c_l is a solution to (**??**) since $F(c_l) = 0$ and by the definition of c_l. If $c_h \ge \overline{c}$, c_h is a solution to (**??**) since $F(c_h) = 1$ and by the definition of c_h. If $\underline{c} < c_l < c_h < \overline{c}$, (**??**) evaluated at $c = c_l$ equals

$$F(c_l)(1-q)(\Omega(\theta H) - \frac{A - c_l(\delta+\lambda)}{q\lambda\alpha}) < 0$$

where the inequality is due to $F(c_l) > 0$, $0 < q < 1$ and $\Omega(\theta H) < q\Omega(L) + (1-q)\Omega(H) = \frac{A - c_l(\delta+\lambda)}{q\lambda\alpha}$. Equation (**??**) evaluated at $c = c_h$ equals

$$(1-F(c_h))(q\Omega(L) + (1-q)\Omega(H) - \frac{A - c_h(\delta+\lambda)}{q\lambda\alpha}) > 0$$

where the inequality is due to $F(c_h) < 1$, $0 < q < 1$ and $\Omega(\theta H) = \frac{A - c_h(\delta+\lambda)}{q\lambda\alpha} < q\Omega(L) + (1-q)\Omega(H)$. By Intermediate Value Theorem, there exists a value $c_1^v \in [c_l, c_h]$ for which there is a solution to (**??**). This establishes existence of a solution.

We can identify firm 2's cost threshold, c_2^v, following similar steps as above. Since the firms are symmetric and definitions of c_1^v, A, and Ω_I are independent of c_2^v, $c_2^v = c_1^v = c^v$.

Lemma 3. *Suppose that the support of c is $[0, \infty)$. Under assumption (**??**),*

(i) Under mandatory disclosure, the learning threshold is

$$c^m = \frac{\pi(q\Delta_{L\emptyset}^m + (1-q)\Delta_{H\emptyset}^m) + \lambda\tau(1-\theta)\mu}{\delta+\lambda}. \tag{31}$$

This threshold is strictly increasing with $\Delta_{L\emptyset}^m$, $\Delta_{H\emptyset}^m$, and τ, and is invariant with respect to α and Δ_{LH}^m.

(ii) Under full voluntary disclosure, the learning threshold equals

$$c^v = \frac{\pi(q\Delta^v_{L\emptyset} + (1-q)\Delta^v_{H\emptyset}) + \lambda\tau(1-\theta)\mu}{\delta+\lambda}. \tag{32}$$

This threshold is strictly increasing with $\Delta^v_{L\emptyset}$, $\Delta^v_{H\emptyset}$, and τ, and is invariant with respect to α and Δ^v_{LH}.

(iii) Under partial voluntary disclosure, the learning threshold equals

$$c^v = \frac{A + q\lambda\tau\alpha g_I}{\delta+\lambda} \tag{33}$$

where

$$A = q\pi\Delta^v_{L\emptyset} + \lambda\tau((1-\alpha)\mu - \theta qL - (1-q)(1-\alpha)\theta H) \tag{34}$$

and

$$g_I = \frac{(1-F(c^v))\mu + F(c^v)(1-q)\theta H}{1-F(c^v)q}. \tag{35}$$

The learning threshold is unique when $\frac{f(c)}{1-F(c)q}$ increases with c. When the threshold is unique, it is strictly increasing with $\Delta^v_{L\emptyset}$, τ, increasing with α (strictly when $\alpha \in (0,1)$), and is invariant with respect to $\Delta^v_{H\emptyset}$ and Δ^v_{LH}.

Proof of Lemma ??: *Mandatory Disclosure:* The sensitivity results follow from taking the derivative of c^m with respect to the model parameters: $dc^m/d\Delta^m_{L\emptyset} = \pi q/(\lambda+\delta) > 0$, $dc^m/d\Delta^m_{H\emptyset} = \pi(1-q)/(\lambda+\delta) > 0$, $dc^m/d\Delta^m_{LH} = 0$, $dc^m/d\tau = \lambda(1-\theta)\mu/(\delta+\lambda) > 0$ and $dc^m/d\alpha = 0$. Full voluntary disclosure results also follow from the analysis above.

Partial Voluntary Disclosure: Using (**??**) to rewrite (**??**), the threshold for learning under partial voluntary disclosure c^v is found from

$$R = (1-F(c^v))(\mu - \frac{c^v(\delta+\lambda) - A}{q\lambda\tau\alpha}) + F(c^v)(1-q)(\theta H - \frac{c^v(\delta+\lambda)-A}{q\lambda\tau\alpha}) = 0. \tag{36}$$

g_I is a weighted average of μ and θH, so it should satisfy $\mu \le g_I \le \theta H$. Let us define $c_l := \frac{A+q\lambda\tau\alpha\mu}{\delta+\lambda}$ and $c_h := \frac{A+q\lambda\tau\alpha\theta H}{\delta+\lambda}$. c_l is in the support of c since

$$\begin{aligned} &A + q\lambda\tau\alpha\mu = q\pi\Delta^v_{L\emptyset} + \lambda\tau((1-\alpha)\mu - \theta qL - (1-q)(1-\alpha)\theta H) + q\lambda\tau\alpha\mu \\ &= q\pi\Delta^v_{L\emptyset} + \lambda\tau\Big((1-\alpha)\mu + q\alpha\mu - \theta qL - (1-q)(1-\alpha)\theta H\Big) \\ &= q\pi\Delta^v_{L\emptyset} + \lambda\tau\Big((1-q)(1-\alpha)(\mu-\theta H) + q\mu - q\theta L\Big) = q\pi\Delta^v_{L\emptyset} + \lambda\tau(\mu(1-\theta) + (1-q)\alpha(\theta H - \mu)) > 0 \end{aligned} \tag{37}$$

as a result of $\mu > 0$, $\theta < 1$ and $\theta H > \mu$. Since $c_h \ge c_l$, c_h is also in the support of c. Equation (**??**) evaluated at c_l equals $F(c_1)(1-q)(\theta H - \frac{c_l(\delta+\lambda)-A}{q\lambda\tau\alpha}) > 0$ since $F(c_l) > 0$, $0 < q < 1$ and $\theta H > \mu = \frac{c_l(\delta+\lambda)-A}{q\lambda\tau\alpha}$. Equation (**??**) evaluated at c_h equals $(1-F(c_h))(\mu - \frac{c_h(\delta+\lambda)-A}{q\lambda\tau\alpha}) < 0$ since $F(c_h) < 1$, $0 < q < 1$ and $\theta H = \frac{c_h(\delta+\lambda)-A}{q\lambda\tau\alpha} > \mu$. By Intermediate Value Theorem, there exists a value $c^v \in [c_l, c_h]$ for which there is a solution to (**??**). Moreover, if this solution is unique,

$$\frac{\partial R}{\partial c}|_{c=c^v} < 0. \tag{38}$$

We show that a sufficient condition for uniqueness is that $\frac{f(c)}{1-F(c)q}$ increases with c in the Online Appendix. We apply the Implicit Function Theorem to check the effect of the model parameters on c^v. So,

$$\frac{\partial R}{\partial \tau} = (1-F(c^v)q)\frac{c^v(\delta+\lambda)-A}{q\lambda\tau^2\alpha} + (1-F(c^v)q)\frac{\frac{dA}{d\tau}}{q\lambda\tau\alpha}.$$

Using $\frac{dA}{d\tau} = \lambda((1-\alpha)\mu - \theta qL - (1-q)(1-\alpha)\theta H)$, we can rewrite $\frac{\partial R}{\partial \tau}$ as

$$\frac{\partial R}{\partial \tau} = (1-F(c^v)q)\frac{c^v(\delta+\lambda)-q\pi\Delta^v_{L\emptyset}}{q\lambda\tau^2\alpha}.$$

The nominator of this expression can be simplified using the relation $c^v(\lambda+\delta) = A + q\lambda\tau\alpha g_I$:

$$\begin{aligned} c^v(\delta+\lambda) - q\pi\Delta^v_{L\emptyset} &= q\lambda\tau\alpha g_I + \lambda\tau(1-\alpha)\mu - \lambda\tau\theta qL - (1-q)(1-\alpha)\lambda\tau\theta H \\ &= q\lambda\tau\alpha(g_I - \theta L) + \lambda\tau(1-\alpha)(\mu - q\theta L - (1-q)\theta H) > 0. \end{aligned} \tag{39}$$

The last inequality is due to $g_I \geq \mu = qL + (1-q)H$ and $\theta < 1$. Hence, $\frac{dc^v}{d\tau} = -\frac{\partial R}{\partial \tau}/\frac{\partial R}{\partial c^v} > 0$.
Next, we look into the effect of α on c^v. $\frac{\partial R}{\partial \alpha}$ can be written as

$$\frac{\partial R}{\partial \alpha} = (1-F(c^v)q)\frac{c^v(\delta+\lambda)-A}{q\lambda\tau\alpha^2} + (1-F(c^v)(q))\frac{\frac{dA}{d\alpha}}{q\lambda\tau\alpha},$$

and $\frac{dA}{d\alpha} = \lambda\tau(1-q)\theta H - \lambda\tau\mu$. Then,

$$\begin{aligned} -\frac{A}{q\lambda\tau\alpha^2} + \frac{\frac{dA}{d\alpha}}{q\lambda\tau\alpha} &= \frac{-q\pi\Delta^v_{L\emptyset} - \lambda\tau(1-\alpha)\mu + \lambda\tau\theta qL + \lambda\tau(1-q)(1-\alpha)\theta H + \lambda\tau\alpha(1-q)\theta H - \lambda\tau\alpha\mu}{q\lambda\tau\alpha^2} \\ &= \frac{-q\pi\Delta^v_{L\emptyset} + \lambda\tau\theta qL + \lambda\tau(1-q)\theta H - \lambda\tau\mu}{q\lambda\tau\alpha^2} = \frac{-q\pi\Delta^v_{L\emptyset} - \lambda\tau(1-\theta)\mu}{q\lambda\tau\alpha^2}. \end{aligned}$$

Hence,

$$\frac{\partial R}{\partial \alpha} = \frac{c^v(\lambda+\delta) - q\pi\Delta^v_{L\emptyset} - \lambda\tau(1-\theta)\mu}{q\lambda\tau\alpha^2}(1-F(c^v)q).$$

Using the definition of A, the nominator can be written as

$$\begin{aligned} & c^v(\lambda+\delta) - q\pi\Delta^v_{L\emptyset} - \lambda\tau(1-\theta)\mu = \lambda\tau(1-\alpha)\mu - \lambda\tau q\theta L - \lambda\tau(1-q)(1-\alpha)\theta H + \lambda\tau q\alpha g_I - \lambda\tau(1-\theta)\mu \\ & = -\lambda\tau q\theta L - \lambda\tau(1-q)(1-\alpha)\theta H + \lambda\tau q\alpha g_I - \lambda\tau\alpha\mu + \lambda\tau\theta\mu \\ & = \lambda\tau\alpha(1-q)\theta H + \lambda\tau\alpha q g_I - \lambda\tau\alpha\mu = \lambda\tau\alpha(1-q)(\theta H - \mu) + \lambda\tau\alpha q(g_I - \mu) \geq 0. \end{aligned}$$

Hence, $\frac{\partial R}{\partial \alpha} \geq 0$ and $\frac{dc^v}{d\alpha} \geq 0$ (with $\frac{dc^v}{d\alpha} > 0$ when $0 < \alpha < 1$).
Finally, we consider the effect of $\Delta^v_{L\emptyset}$. $\frac{\partial R}{\partial \Delta^v_{L\emptyset}} = (1-F(c^v)q)\frac{q\pi}{q\lambda\tau\alpha} > 0$. Therefore, $\frac{dc^v}{d\Delta^v_{L\emptyset}} > 0$. Since $\Delta^v_{H\emptyset}$ and Δ^v_{LH} do not affect c^v, $\frac{dc^v}{d\Delta^v_{H\emptyset}} = 0$ and $\frac{dc^v}{d\Delta^v_{LH}} = 0$.

Proof of Proposition ??: Recall that $|\Delta^v_{HL}|$ is the loss of market share as a result of disclosing H when the competitor discloses L and that $\Delta^v_{HL} = -\Delta^v_{LH}$ and $\Delta^m_{HL} = -\Delta^m_{LH}$. Under a full voluntary disclosure equilibrium, firm 1's objective value (**??**) after learning that impacts are high can be found from (**??**) (after substituting for customer response parameters under voluntary disclosure). If firm 1 deviates and chooses not to disclose after finding out impacts are high, its expected market share is $\frac{1}{2} - F(c^v)q\Delta^v_{L\emptyset} - F(c^v)(1-q)\Delta^v_{H\emptyset}$ since firm 2 will learn and disclose that its impact is low with probability $F(c^v)q$, will learn and disclose that its impact is high with probability $F(c^v)(1-q)$ and will not learn or disclose with probability $1-F(c^v)$. Firm 1's discounted profit and valuation from not disclosing high impact is given by

$$\frac{\pi(\frac{1}{2} - F(c^v)q\Delta^v_{L\emptyset} - F(c^v)(1-q)\Delta^v_{H\emptyset}) + \lambda\alpha\Omega_I + \lambda(1-\alpha)\Omega(\theta H)}{\delta+\lambda}. \tag{40}$$

Here, $\Omega_I = q\Omega(L) + (1-q)\Omega(H)$ since the investors infer that firm 1 did not learn observing nondisclosure. Full disclosure can occur in equilibrium if and only if the objective value from disclosing high impact is greater; i.e.,

$$-\pi F(c^v)q\Delta^v_{LH} + \pi(1-F(c^v))\Delta^v_{H\emptyset} + \lambda\Omega(\theta H) \geq -\pi F(c^v)(1-q)\Delta^v_{H\emptyset} - \pi F(c^v)q\Delta^v_{L\emptyset} + \lambda(\alpha\Omega_I + (1-\alpha)\Omega(\theta H)).$$

This expression can be simplified to

$$\overline{\alpha} = \frac{\pi(F(c^v)q(\Delta^v_{L\emptyset} - \Delta^v_{LH}) + (1-F(c^v)q)\Delta^v_{H\emptyset})}{\lambda(\Omega_I - \Omega(\theta H))} \geq \alpha,$$

where $\Omega_I = q\Omega(L) + (1-q)\Omega(H)$. In the expression above for $\overline{\alpha}$, $-\Delta^v_{LH}$ can be replaced with Δ^v_{HL}. Since c^v is independent of α under full disclosure (by Lemma **??**), this establishes the result. Note that c_v is invariant to Δ^v_{LH} under full voluntary disclosure (by Lemma **??**), and $d\overline{\alpha}/d|\Delta^v_{HL}| = -\pi F(c^v)q/(\lambda(\Omega_I) - \Omega(\theta H)) \leq 0$.

Proof of Theorem ??: Lemma 2 shows that a firm learns if and only if its cost of doing so is below a threshold. We now show that a mandate for disclosure lowers this threshold.

Suppose that the firms disclose information fully under voluntary disclosure. Then, (**??**) and (**??**) depend only on the comparison of customer response parameters under voluntary and mandatory disclosure. Then, (**??**) and (**??**) imply that voluntary disclosure threshold is higher.

Now suppose both firms disclose only upon learning that impacts are low. From equations (**??**) and (**??**), the difference between c^v and c^m is given by

$$\begin{aligned} c^v - c^m = &\Big(\frac{\pi(q(\Delta^v_{L\emptyset} - \Delta^m_{L\emptyset}) - (1-q)\Delta^m_{H\emptyset})}{\delta+\lambda}\Big) \\ &- \frac{\lambda\alpha q\Omega_I + \lambda(1-\alpha)(q\Omega(L) + (1-q)\Omega(H) - q\Omega(\theta L) - (1-q)\Omega(\theta H)) - \lambda\alpha q\Omega(\theta L)}{\lambda+\delta} \\ &+ \frac{\lambda(q\Omega(L) + (1-q)\Omega(H) - q\Omega(\theta L) - (1-q)\Omega(\theta H))}{\lambda+\delta}, \end{aligned} \tag{41}$$

where Ω_I is defined as in (**??**) in Lemma **??**.

Denoting $p = (1-F(c^v))$, we can rewrite the nominator of the sum of the second and third terms as

$$\begin{aligned} &-[\lambda\alpha q\Omega_I + \lambda(1-\alpha)(q\Omega(L) + (1-q)\Omega(H) - q\Omega(\theta L) - (1-q)\Omega(\theta H)) - \lambda\alpha q\Omega(\theta L)] \\ &+ \lambda(q\Omega(L) + (1-q)\Omega(H) - q\Omega(\theta L) - (1-q)\Omega(\theta H)) \\ &= -\lambda\alpha(q\Omega_I - (q\Omega(L) + (1-q)\Omega(H) - q\Omega(\theta L) - (1-q)\Omega(\theta H)) - q\Omega(\theta L)) \\ &= -\lambda\alpha\Big(q\frac{(1-p)q\Omega(L) + (1-p)(1-q)\Omega(H) + p(1-q)\Omega(\theta H)}{1-pq} - q\Omega(L) - (1-q)\Omega(H) + q\Omega(\theta L) + (1-q)\Omega(\theta H) - q\Omega(\theta L)\Big) \\ &= -\frac{\lambda\alpha}{1-pq}\Big((1-p)q^2\Omega(L) - q\Omega(L) + pq^2\Omega(L) + q(1-p)(1-q)\Omega(H) + pq(1-q)\Omega(\theta H) - (1-pq)(1-q)\Omega(H) \\ &+ (1-pq)(1-q)\Omega(\theta H)\Big) \\ &= -\frac{\lambda\alpha}{1-pq}\Big(q(q-1)\Omega(L) + (1-q)\Omega(\theta H) - (1-q)^2\Omega(H)\Big) = \frac{\lambda\alpha}{1-pq}(1-q)(q\Omega(L) + (1-q)\Omega(H) - \Omega(\theta H)). \end{aligned}$$

Since $q\Omega(L)+(1-q)\Omega(H)\geq\Omega(\theta H)$, the sum of second and third terms in (**??**) are nonnegative. We also have $\Delta^v_{L\emptyset}\geq\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}\leq 0$, and the first term in (**??**) is nonnegative. c^v-c^m is nonnegative and the managers learn with a higher probability under voluntary disclosure. This implies that, due to impact reduction benefits from learning, mandate leads to (weakly) higher impacts for all possible realizations of learning cost and impact. This result can be extended to equilibria in mixed strategies as well (shown in the Online Appendix).

Proof of Propositions ?? and ??: We check how the difference in the environmental performance under voluntary and mandatory disclosure changes with respect to the model parameters. We note that c^v is increasing with α under partial voluntary disclosure while c^m is independent of α in Lemma **??**. Hence, the increase in impact due to a mandate weakly increases with α for all possible realizations of learning cost and impact. Lemma **??** also shows that under partial voluntary disclosure c^v is increasing with $\Delta^v_{L\emptyset}$ and is independent of $\Delta^v_{H\emptyset}$ while c^m is increasing with $\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}$. Therefore, the increase in impact due to a mandate is increasing with $\Delta^v_{L\emptyset}$, is independent of $\Delta^v_{H\emptyset}$, and decreasing with $\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}$.

Proof of Proposition ??: Theorem 1 implies that a firm that does not learn in the voluntary disclosure scenario will not learn in the mandatory disclosure scenario. It remains to show that for a firm that does not learn, expected profit and valuation are higher in the mandatory disclosure scenario than the voluntary disclosure scenario.

Consider the mandatory disclosure scenario. Observing no disclosure, investors know that the firm did not learn, so expected discounted profit and expected valuation are equal and given by

$$E_{G_1,d_2}[\Pi_1|g_1,d_2]=\frac{\pi(\frac{1}{2}-F(c^m)(q\Delta^m_{L\emptyset}+(1-q)\Delta^m_{H\emptyset}))-\lambda\tau\mu}{\delta+\lambda}, \tag{42}$$

according to Lemma 1 with $p=F(c^m)$.

Now consider a partial disclosure equilibrium in the scenario with voluntary disclosure. Lemma 1 with $p=F(c^v)$ implies that expected discounted profit is given by

$$\frac{\pi(\frac{1}{2}-F(c^v)q\Delta^v_{L\emptyset})-\lambda\tau\mu}{\delta+\lambda}, \tag{43}$$

and expected valuation is given by

$$\frac{\pi(\frac{1}{2}-F(c^v)q\Delta^v_{L\emptyset})-\lambda\tau g_I}{\delta+\lambda}. \tag{44}$$

Both (**??**) and (**??**) are smaller than (**??**), because $g_I\geq\mu$, $c^v\geq c^m$ (by Theorem 1), $\Delta^v_{L\emptyset}\geq\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}\leq 0$. We have restricted attention to pure strategy equilibria so, by Lemma 2, it remains only to consider a full voluntary disclosure equilibrium. Observing no disclosure, investors know that the firm did not learn, so expected discounted profit and expected valuation are equal, and given by (**??**) except that c^v is substituted for c^m, and $\Delta^v_{L\emptyset}$ and $\Delta^v_{H\emptyset}$ are substituted for $\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}$. Those substitutions reduce the value of (**??**) because $c^v\geq c^m$ (by Theorem 1), $\Delta^v_{L\emptyset}\geq\Delta^m_{L\emptyset}$ and $\Delta^v_{H\emptyset}\geq 0\geq\Delta^m_{H\emptyset}$.

Proof of Propositions ?? and ??: It suffices to compare the firm's discounted cost from its impact and the investors' expectation of what that cost would be to calculate the investors' expected disutility under both mandatory and voluntary disclosure scenarios.

Comparing firm's cost of impact and investors' expectation of the cost of impact for each possible realization of cost and impact, we calculate the investors' utility in expectation under mandatory disclosure to be

$$-K(1-F(c^m))[q(\mu-L)^2+(1-q)(\mu-H)^2]=-KU^m \tag{45}$$

where $K=(\lambda\tau/(\lambda+\delta))^2$.

Similarly, investors' utility in expectation under voluntary disclosure is found to be

$$-K[F(c^v)(1-q)(g_I-\theta H)^2+(1-F(c^v))\Big(q(g_I-L)^2+(1-q)(g_I-H)^2\Big)]=-KU^v. \tag{46}$$

We compare investors' expected utility under voluntary and mandatory disclosure and examine how the comparison changes with respect to α. The comparison of the two expressions do not depend on K. We also omit the negative sign at the beginning of both expressions. Note that $\frac{dU^v}{d\alpha}=\frac{\partial U^v}{\partial c^v}\frac{dc^v}{d\alpha}+\frac{\partial U^v}{\partial g_I}\frac{dg_I}{d\alpha}$. $\frac{\partial U^v}{\partial g_I}=0$ from the definition of g_I ((**??**) in Lemma **??**). Hence,

$$\begin{aligned}\frac{\partial U^v}{\partial c^v}&=f(c^v)(1-q)(g_I-\theta H)^2-f(c^v)(q(g_I-L)^2+(1-q)(g_I-H)^2)\\&=f(c^v)(1-q)((g_I-\theta H)^2-(g_I-H)^2)-f(c^v)q(g_I-L)^2<0.\end{aligned} \tag{47}$$

The last inequality is due to $\mu\le g_I\le\theta H\le H$, $q>0$ and $f(\cdot)$ being continuous. Then, $\frac{dU^v}{d\alpha}<0$ since $\frac{dc^v}{d\alpha}>0$ in the interval $\alpha\in(0,1)$ as shown in Lemma **??**. Since $\frac{dc^m}{d\alpha}=0$, $\frac{dU^m}{d\alpha}=0$. We define

$$\hat{\alpha}:=\min(\max(0,\tilde{\alpha}),1),$$

where $\tilde{\alpha}$ is the value of α where U^v and U^m are equal, keeping other parameters constant. $\hat{\alpha}$ must be unique since $\frac{U^v(c^v(\alpha))}{d\alpha}<0$ in the interval $\alpha\in(0,1)$. When $\alpha<\hat{\alpha}$ ($\alpha>\hat{\alpha}$), $U^v>U^m$ ($U^v<U^m$).

For any value of α, c^v increases with $\Delta^v_{L\emptyset}$ (by Lemma **??**) and consequently U^v decreases with $\Delta^v_{L\emptyset}$. Then, $\hat{\alpha}$ is decreasing with $\Delta^v_{L\emptyset}$. c^m is increasing with $\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}$ (by Lemma **??**) and consequently U^m is decreasing $\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}$. Therefore, $\hat{\alpha}$ is increasing with $\Delta^m_{L\emptyset}$ and $\Delta^m_{H\emptyset}$.

We now turn our attention to Proposition **??**. To prove that investors' utility is increasing in τ under both mandatory and voluntary disclosure scenarios, we use (**??**) and (**??**) above. The derivative of U^v with respect to τ is $\frac{dU^v}{d\tau}=\frac{\partial U^v}{\partial c^v}\frac{dc^v}{d\tau}+\frac{\partial U^v}{\partial g_I}\frac{dg_I}{d\tau}$. From the definition of g_I (**??** in Lemma **??**), $\frac{\partial U^v}{\partial g_I}=0$ and by (**??**), $\frac{\partial U^v}{\partial c^v}<0$. The derivative of U^m with respect to τ is $\frac{dU^m}{d\tau}=\frac{\partial U^m}{\partial c^m}\frac{dc^m}{d\tau}$. $\frac{\partial U^m}{\partial c^m}=-f(c^m))(q(\mu-L)^2+(1-q)(\mu-H)^2)<0$ and $\frac{dc^m}{d\tau}>0$ in Lemma **??**. Therefore, $\frac{dU^m}{d\tau}<0$ and investors' utility increases with τ. We can show that the result holds for full voluntary disclosure by following the analysis of mandatory disclosure.

By Lemma **??**, $\frac{d\hat{c}}{d\tau}>0$ for both voluntary and mandatory disclosure, meaning that the firm chooses to learn with a higher probability under a higher τ. Therefore, a firm's impact is weakly decreasing in τ under all possible realizations of learning cost and impact and under both mandatory and voluntary disclosure scenarios.

Appendix B: Additional Experimental Results and Experiments

In addition to the experiments described in Section **??**, we also ran an additional experiment where disclosures made by the firm with higher emissions were modified to include more impact information. Tables **??** and Table **??** summarize the results for the voluntary and mandatory case respectively. The numbers for Control are obtained from taking the first 164 readings from the Control treatment in our earlier experiment described in the main text. For the scenarios in this experiment, Firm 1 disclosed low emissions while Firm 2 disclosed high emissions. We modify each treatment by having Firm 2 make additional disclosures.

Under the scenario "Breakdown", Firm 2 disclosed a percentage breakdown of lifecycle emissions at each stage in the supply chain. Under "Assumptions", Firm 2 stated that measuring total lifecycle emissions required making assumptions and it had used the most conservative estimates that made the calculated emissions higher for its product. Under "Leadership", Firm 2 stated that in 2008, it had become the first company in the computer industry to disclose lifecycle emissions information for all its products. Under "Combination", Firm 2 made all of the above additional disclosure statements. The p-values come from a one-sided proportion test with Control. The surveys are reproduced in the Online Appendix.

The results in the tables show that disclosing additional information about the breakdown of emissions, a firm's leadership in disclosure, and a combination of these could mitigate a firm's loss in market share even if its product had higher emissions than a competitor's. These suggest that firms should invest in learning make disclosures as early and as detailed as possible. This would allow them to gain market share before the competitor discloses and also mitigate their market share loss if their competitor discloses lower emissions.

Scenario	**Percentage Choosing**		**p-value**	**Total**
	Firm 1	**Firm 2**		
Control	0.50	0.50		164
Breakdown	0.54	0.46	0.269	161
Assumptions	0.68	0.32	0.001**	157
Leadership	0.50	0.50	0.500	168
Combination	0.49	0.51	0.500	162

Table 5 Scenarios where two firms voluntarily disclose emissions information with Firm 1 making additional disclosures and subsequent choice of laptop.

Scenario	**Percentage Choosing**		**p-value**	**Total**
	Firm 1	**Firm 2**		
Control	0.50	0.50		164
Breakdown	0.55	0.45	0.192	168
Assumptions	0.65	0.35	0.003**	157
Leadership	0.53	0.47	0.500	166
Combination	0.46	0.54	0.254	164

Table 6 Scenarios where two firms voluntarily disclose emissions information with Firm 1 making additional disclosures and subsequent choice of laptop.