**Carrot or Stick? Supplier Diversity and its Impact on Carbon Emission Reduction Strategies**

Herbie Baiyang Huang
Doctoral Student
Kenan-Flagler Business School, University of North Carolina Chapel Hill
5500 McColl Building, Chapel Hill, NC 27599, USA
Phone: 919-525-8001, e-mail: herbie_huang@kenan-flagler.unc.edu

Sriram Narayanan
Kesseler Family Endowed Faculty Fellowship in Supply Chain Management
The Eli Broad Graduate School of Management, Michigan State University
Department of Supply Chain Management
N370 North Business Complex, East Lansing, MI 48824, USA
Phone: 517-432-6432, e-mail: Narayanan@broad.msu.edu

Jayashankar M. Swaminathan
GlaxoSmithKline Distinguished Professor of Operations
Kenan-Flagler Business School, University of North Carolina Chapel Hill
4717 McColl Building, Chapel Hill, NC 27599, USA
Phone: 919- 843-8341, e-mail: msj@unc.edu

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**Abstract**

**Problem definition:** This study examines the antecedents and consequences of knowledge sharing and monitoring based governance strategies on emissions reduction. We theorize, and empirically test, the impact of supply base diversity in industry and geographic locations on the governance strategy choices.

**Academic/Practical relevance:** Engaging in emissions reduction is an important priority for companies large and small. Few empirical studies have systematically examined supply chain governance strategies with large scale empirical data. Such a data-based analysis may provide managers with clues to implementing and assessing the efficacy of these strategies.

**Methodology:** We use a diverse set of data sources that include CDP, Compustat, Factset, and Trucost, among others. We used a multinomial logit framework to model the strategies choices. To evaluate implications of governance strategies, we used a treatment effect model to provide an estimate of the impact of adopting different governance strategies on the GHG emissions intensity changes.

**Results:** We find that sector and regional diversity both have a significant impact on emissions reduction strategies, yet their direct and interactive impacts are different. Regarding consequences, we find that engaging suppliers is associated with GHG emissions reduction for both buyers and suppliers. Specifically, monitoring (knowledge sharing) can lower total emissions intensity by 2.6% (3%) for the firm and 3.8% (1.3%) for supplier.

**Managerial implications:** Our findings provide insights for managers making decisions about GHG emissions reduction strategy and assess its magnitude.

**Keywords**: Supplier Diversity; Supply Chain Governance; GHG Emissions Reduction; Natural Language Processing

**History**: Recent Update Nov 30, 2019

## 1. Introduction

Global firms are increasingly motivated to reduce greenhouse gas (GHG) emissions. They not only face pressures from regulators (Reid and Toffel 2009), consumers (Kraft et al. 2018), and investors (Jira and Toffel 2013) but also realize that their environmental performance is critical to their financial performance and long-term survival (Jacobs 2014). As the climate crisis increasingly becomes one of the world's greatest existential threats, global companies seeking high-impact solutions are realizing that the greatest potential for reduction of emissions lies in their supply chains, which they do not directly control and yet account for 80% of their total emissions on average (Carbon Disclosure Project 2017).

The case of Apple Inc. provides some insight into the magnitude of supply chain emissions in relation to the company. It was calculated that 2% of the GHG emissions released during the production of an iPhone 8 happened inside Apple facilities (Apple Inc, 2016). The rest of the emissions occurred in the context of the overall supply chain. Besides Apple, there are several other such examples: Lego Group estimates that 75% of their GHG emissions could be attributed to its suppliers and Wal-Mart attributes over 90% of its total emissions to suppliers (Carbon Disclosure Project, 2015). As a result, firms are striving to develop effective governance strategies for managing supply chain emissions.

Global supply chains often span several industries and geographic regions (Timmer et al. 2014, Baldwin 2012). For example, iPhone value add occurs in countries like Germany (17%), Japan (34%), South Korea (13%), China (3.6%), and several others (Batson 2010). A study of Nokia's cell phone supply chain yielded similar pattern for the Nokia 1200 phone, the value is captured in Finland (8%), other EU area (22%), North America (13.8%) and Asia (45.8%) (Larson et al. 2018). Further, products like cellphones require firms to engage with suppliers in disparate industrial sectors. The bill of materials (BOM) of the Nokia 1200 model revealed that components came from a global supply base and the value was distributed across different industries: specifically, processor (7%), display (12.1%), battery (4.4%), and logistic suppliers and retailers (25%). This diversity creates challenges to reduce emissions (Davis et al. 2011) and requires extensive coordination (Ernst 2002; Kleindorfer and Snir 2001).

Although supply chain governance literature has studied how companies manage their suppliers, current literature does not shed light on how companies implement governance strategies in their supply chains to reduce emissions. As an effort-intensive task (Environmental Protection Agency 2010), reducing emissions requires the imposition of both formal and informal modes of governance across the network. Formal modes of governance in the supply base refer to the controls imposed on suppliers by explicit rules, procedures, and norms that prescribe the rights and obligations of suppliers (Choi and Hong 2002). In environmental governance, formal procedures include setting environmental standards, auditing procedures, establishing codes of conduct, and formalizing processes and/or prescribing restricted materials (e.g., Tachizawa and Wong 2015; Wilding et al. 2012; Miemczyk et al. 2012). These procedures require a firm to monitor their suppliers' GHG emissions. Buyers use formal processes to score suppliers on sustainability as well. In 2015, Apple conducted twenty-one unannounced audits and 25,000 follow-up interviews with workers to ensure compliance with its sustainability standards. Monitoring enabled the company to reduce 13,800 metric tons of GHG emissions (Apple Inc, 2016).

Given the complexity of supply chain governance efforts, firms may also pursue informal approaches in addition to, or instead of, formal controls. Informal controls rely on learning and innovation via information exchange/collaboration between the firm and its supply base (Wilding et al. 2012, Harland and Knight 2001). Examples of informal governance mechanisms include peer-to-peer learning via greenhouse gas (GHG) seminars, non-competitive supplier working groups, assistance with suppliers' logistics and product designs, NGO partnerships, interactive websites, and supplier/industry forums for knowledge sharing (Plambeck et al. 2012). For example, Herman Miller, in implementing the cradle-to-cradle protocol (McDonough and Braungart 2002), worked with suppliers to exchange knowledge and motivated them to be more transparent ( Lee and Bony 2007). Similarly, Walmart launched supplier energy efficiency program (SEEP) in 2008 where knowledge sharing with the top management of the supplier firms was an integral element of the program. These companies exemplify collaborative engagement featuring knowledge sharing with suppliers to reduce GHG emissions.

Both knowledge sharing and monitoring are difficult to implement. The challenge of governance is closely related to the complexity of a given supply chain (Griffis et.al 2017). Our study links this complexity to two forms of diversities (geography and sector composition) that characterize a firm's global supply base. Supply base diversity has explicit implications in the context of the reduction of GHG emissions. Emissions reduction technology and requirements vary widely between industries (Bygrave and Ellis 2003). Thus, firms that source from multiple industry sectors may find it more difficult to implement emission reduction practices that is specific to each one of these industries. Likewise, a buyer firm which sources from many countries and regions faces the challenge of different rules and regulations (Lee and Tang 2018), in addition to political, social and economic uncertainties that can hinder their ability to reduce emissions (Manuj and Mentzer 2008).

Despite the prevalence of both monitoring and knowledge sharing approaches in firms, few empirical studies have systematically examined their efficacy and influence on reducing supply chain emissions. To fill this gap, we examine in this study drivers of knowledge sharing and monitoring, and their consequent impact on emissions reduction. We argue that regional and sectoral diversities in firms' global supply chains have an important role in their choice of implementing knowledge sharing, monitoring, or both. To summarize, we examine the following questions: (1) how does supply chain diversity influence the choice of governance strategies (knowledge sharing and/or monitoring), and (2) what is the impact of these strategies on the actual reduction of greenhouse gases? An amalgamation of multiple databases including those maintained by the Carbon Disclosure Project (CDP), Trucost, Factset, Compustat, and the World Bank, helps us answer these questions.

The remainder of the paper is organized as follows. In §2, we summarize the field's current literature. In §3, we present the empirical strategy to assess the antecedents and consequences of governance strategies and detail the construction of key variables in our empirical model. In §4, we present our results. In §5, we discuss robustness checks. Finally, in §6, we present the implications.

**2. Related Literature**

Prior to developing our hypotheses, we will briefly review the current literature on sustainability and emissions reduction. The broader issue of sustainability has been addressed both analytically and empirically in current literature. Drake and Spinler (2013) discuss the importance of sustainable practices in firms wanting to reduce their natural resource consumption footprint and the need for new technologies or supply chain processes. Among the analytical works, Agrawal and Lee (2019) modeled how a buyer uses sourcing policies to influence suppliers' sustainability performance. Guo et al. (2016) modeled the sourcing decision of buyers who have both responsible and risky types of suppliers. Caro et al (2016) considered audit-penalty mechanisms, and Kraft et al. (2019) examined the investment decisions that buyers make to improve supply chain visibility. While each of these factors is connected to overall sustainability performance, they do not focus on emissions reduction. Similarly, empirical studies in sustainability has examined corporate disclosure in response to consumer and regulatory pressures (Reid and Toffel 2009), customer's valuations of creating supply chain visibility (Kraft et al. 2018), investments in Green IT (Khuntia et al. 2018), impact of cradle-to-cradle closed-loop supply chain on solid waste (Dhanorkar 2018), and adoption of environmental management practices or initiatives (Hardcopf et al. 2019, Jacobs et al. 2010). These studies have not explicitly examined supply chain governance practices.

Within the literature on GHG emissions reduction, existing studies have largely focused on the disclosure of emissions or data quality of emissions. For example, Jira and Toffel (2013) focus on conditions under which firms respond to the CDP survey and share information and found that buyer pressure, as well as the industry from which suppliers are composed, are salient factors in disclosure. Blanco et al. (2016) note that firms (in CDP) are only reporting 22% of their full Scope 3 emissions; Kim and Lyon (2011)'s find an increase in shareholder value from CDP participation and similarly Jacobs (2014) finds a positive link between voluntary emissions reduction and market reaction; Bellamy et al. (2019) created metrics for supply network information access and measured its impact on environmental disclosure. These studies, although important precursors to our study, do not examine the influence of governance practices on emissions reduction.

The third stream of literature focus on governance practices in making supply chains sustainable. These studies primarily pursue qualitative work. Tachizawa and Wong (2015) note that governance in the pursuit of making supply chains environmentally friendly is distinctively more complex compared to traditional supply chains. The primary reason is that environmental activities imply higher hidden risk, harbor more information asymmetry, and are less visible. These require both formal and informal governance mechanisms. Villena (2018) finds three groups of governance patterns in procurement processes for managing supplier sustainability - i.e., assessing, training, and incentivizing. Others such as Formentini and Taticchi (2016) characterize collaborative and non-collaborative governance in examining the sustainability footprint of seven Italian food companies. Hoejmost et al. (2014) surveyed 198 UK-based companies with drivers that influenced firms' coercive and cooperative green supply chain practices. These empirical studies form the basis for the formal and informal governance strategies that this paper examines. However, none of these studies examine supply base complexity as a driver of governance practice implementation or the consequences of these practices on emissions reduction. Given the importance of global supply chains discussed earlier, this is a critical factor. Furthermore, our study is distinct in examining the consequences of implementing these strategies, which is not a focus of the previous empirical and analytical studies in this domain (Lee and Tang 2018).

## 3. Theory Development

### 3.1 Diversity of supply base

Supply chain complexity manifests in many dimensions. Lu and Shang (2017) identify spatial complexity, vertical complexity and horizontal complexity. However, in the context of emissions reduction, we particularly examine two components of this setting: spatial and horizontal. Our focus is on buyers' efforts with their direct supply base given that buyers focus on their immediate supply base with respect to emissions. Further, there are few available data sources that allow us to examine emission reduction governance at multiple tiers of the supply chain. Thus, the focus of this study is two components of supply base diversity: (a) diversities of industry sectors from which suppliers come; and (b) the diversity of suppliers' geographical locations. In addition to examining the independent role of these diversity elements, we also examine their interaction. It is likely that a higher diversity of both supplier sectors and geographic locations makes the administration of the system more complex (Amaral and Uzzi 2007). As supply chains become more complex, it becomes increasingly difficult for buyer firms to engage in knowledge sharing and monitoring behaviors. Choi and Krause (2006) note that more complex supply chains tend to have greater variations in interactions with suppliers. Further, complexity in a supply base can drive up risks in environmental challenges faced by the buying firm (Craighead et al. 2007). These risks can impact the coordination processes used by firms in reducing emissions and can consequently impact their governance approach.

Supply base complexity can substantially influence the implementation of governance practices. First, diversity can be a desirable feature when buyers face the task of GHG emissions reduction with knowledge sharing strategies. Cummings (2004) argues that knowledge sharing is more valuable when workgroups are more structurally diverse. He defines structural diversity in terms of roles and positions of actors. The fundamental rationale is that workgroups that have greater structural diversity expose themselves to more unique sources of knowledge and consequently gain exposure to a variety of approaches to solutions. These unique sources of knowledge directly carry forward in the context of firms, as is seen in other network studies such as Ahuja (2000), who note that a greater number of direct alliances increase a firm's innovative output. These innovative outputs are predicated on relational interactions between partners (Ahuja 2000). These arguments are also applicable in the context of governance for emissions reduction. For example, studies suggest that carbon footprints differ distinctively across different industry sectors of suppliers (Matthews et al. 2008). Thus, when firms have suppliers from multiple distinct industry sectors and geographies, it is likely that exposure to a diverse base of knowledge spurs them to implement more collaborative practices. Further, supply chain literature also suggests that collaborative approaches with suppliers are likely to provide additional impetus for suppliers to help engage in complex problem-solving exercises such as emissions reduction (Dyer and Singh 1998), thus increasing the likelihood of implementing knowledge sharing.

Further, implementing monitoring in a diverse supply base may arise out of necessity. As the industry dispersion of the supply base increases, buyers may find it is beneficial to monitor suppliers to incentivize them to implement practices that result in emissions reduction and prevent them from hiding information about unsafe practices or conditions (Plambeck and Taylor 2015). As the supply base gets increasingly diverse in sectors and geographic regions supplier actions may become less visible to the buyer. Monitoring, then, can help in creating a reporting framework that facilitates emissions reduction.

Finally, as the supply base grows in the diversity of sectors and geographies, they are most likely to have suppliers that need additional help to reduce emissions. In studying emissions reduction among suppliers of Hyundai Motors, Lee (2011) note that small and medium enterprises were less likely to cooperate and adopt emissions reduction strategies. Specifically, Lee (2011) finds that "suppliers had little knowledge or measurement tools of carbon footprint" (Lee 2011, p. 1221). Such suppliers are more likely to need both knowledge sharing and monitoring.

Overall, based on these arguments, we hypothesize that as suppliers increasingly come from different industries and regions, firms are more likely to implement knowledge sharing and/or monitoring-based governance strategies as opposed to doing nothing.

***Hypothesis 1a.*** *As the supply base becomes more diverse across sectors and geographic regions, firms are more likely to monitor their suppliers.*

***Hypothesis 2a.*** *As the supply base becomes more diverse across sectors and geographic regions, firms are more likely to share knowledge with their suppliers.*

Just as diversity is likely to result in a greater likelihood of implementation of knowledge sharing and monitoring, it is also plausible that diversity may make implementing governance practices difficult. First, the immediate implication of an increase in supplier industry composition is a greater coordination cost. Kim and Worrell (2002) note that industrial emissions are substantially different across countries in the iron and steel industries. Similarly, Bradford and Fraser (2007) find that energy use was different across suppliers in different sectors. With such variance in energy production and consumption, coordinating a GHG monitoring system can be challenging. This is likely true in other industries as well. An immediate consequence of this complexity is that firms need to invest greater resources. Lee (2011) note that supplier's lack of knowledge to reduce emissions reduction. It is likely that greater diversity in sectors and geographies may deter buyers from investing in collaboration and monitoring infrastructures.

Furthermore, both region and country diversity create frictions in knowledge sharing. Different countries may attain their energy from different mixes of sources (e.g. coal and solar), causing differences in their relative prices (Organisation for Economic Co-operation and Development, 2014), and policies for energy consumption. A solution for production optimization that works for a country with a carbon tax is not the same as a solution for a country with carbon trades (Anand and Giraud-Carrier 2016, Kroes 2012). For example, Starbucks has different strategies in place with its coffee suppliers in countries like Indonesia than with their coffee mugs suppliers in China. Building on these arguments, we argue that the diversity of a supply base increases coordination costs and may overwhelm and deter buyers from pursuing any governance method. Accordingly, we hypothesize:

***Hypothesis 1b:*** *As the supply base becomes more diverse across sectors and geographic regions, firms are less likely to monitor their suppliers.*

***Hypothesis 2b:*** *As the supply base becomes more diverse across sectors and geographic regions, firms are less likely to share knowledge with their suppliers.*

**3.2 Interaction of diversities**

A key feature of the modern global supply chain is its complexity across multiple dimensions. We discuss the interactive influence of increasing both the diversity of sectors from which suppliers come and the diversity of supplier geographic locations on the choice of supply chain governance. An increasing level of diversity on both dimensions can exert a synergistic effect in implementing monitoring and knowledge sharing. The underlying rationale is as follows:

First, more complex supply chains need greater coordination. Monitoring and Knowledge Sharing are key instruments of coordination in larger supply chains with respect to emissions reduction.

As the overall diversity within a supply chain increases the burden to coordinate knowledge across the supply chain is likely to increase. For example, emission reduction targets may differ in regions according to the ceilings that various countries mandate. These credits are more likely to require additional knowledge sharing to understand and facilitate emission reduction.

The complexities of management grow with additional sources of uncertainties in supply chains where firms also come from different industries and have differential resource endowments. Specifically, greater industry diversity in addition to regional diversity puts an additional burden on buyers to increase the visibility needed to manage the supply chain. For example, Plambeck et al. (2012) note that Walmart – which has a global and diverse supply chain – employs both engagement and monitoring to help rationalize GHG emissions. Similarly, Apple conducted unannounced audits and follow-up interviews with workers to ensure compliance with its sustainability standards in 2015 (Apple Inc 2016).

Managing these differential resource endowments is more likely to spur firms to work with their suppliers to collaboratively reduce footprint, in addition to pursuing approaches to monitoring suppliers, and simultaneously, monitoring emissions reduction and to hold suppliers accountable. Similar to Walmart and Apple, large firms like Hyundai, that have a global base of suppliers that come from several industries, focus on not only monitoring suppliers through different footprint measurement tools but also develop methods to calculate the footprint of different products (Lee 2011). Overall, we believe the arguments that high diversity levels in the supply chain are likely to trigger increased use of monitoring strategies, knowledge sharing strategies, or both. Thus, we hypothesize:

***H3A:*** *Sector diversity and regional diversity in the supply chain will positively interact and increase the likelihood of implementing governance practices.*

In distinct contrast to arguments presented in support of the positive interaction between sectoral and regional diversity, it is likely that they may also have a negative interaction effect. Kraft et al. (2017) studied the relationship between visibility and buyers' responses to improve suppliers' sustainability. They demonstrate that there is no one-size-fits-all prescription. Depending on what the buyer already observes about its suppliers, they may increase or decrease its governing efforts. Thus, it is likely that increased complexity may also reduce a firm's propensity to share knowledge and to monitor suppliers. Specifically, high levels of supply chain complexity (diversity) reduce visibility. While companies bend to stakeholder pressures to adopt environmental measures, they may find it more difficult to implement strategies to actively pursue emission reductions. These can be attributed to the difficulty of collecting necessary knowledge and the challenge of understanding regulations across different sectors and regions.

Second, as the overall complexity of the supply base increases, firms may need to adopt a wait and see approach in order to understand how to implement governance measures. Such an approach allows firms to better adjust measures to their supply base and it may result in a reduced propensity to implement knowledge sharing and monitoring, particularly under high levels of complexity. This is consistent with arguments (Kraft et al. 2017) that firms may adjust governance efforts based on the overall characteristics of the supply base. Based on this, we hypothesize:

***H3B:*** *Sector diversity and regional diversity in the supply chain will negatively interact, and will decrease the likelihood of the implementation of governance practices.*

### 3.3 Implication of governance strategies

In addition to antecedents, we now present arguments for the consequences of knowledge sharing and monitoring on GHG emissions reductions, for both the buyers' supply base and the buying firm.

#### 3.3.1 On supplier emissions

We expect that buyers' pursuit of supplier engagement reduces suppliers' GHG emissions as intended, whether the strategy is monitoring or knowledge sharing based. Knowledge sharing is a form of supplier development that equips suppliers with know-how. Monitoring is an important tool to ensure supplier compliance, as studies have suggested. Babich and Tang (2012) suggest that monitoring deters suppliers from food adulteration. Chen and Lee (2016) suggest monitoring as an approach to reducing risks of supplier responsibility in sustainability. Caro et al. (2018) modeled the benefit of joint or shared audits of suppliers' safety measures; Zhang et al. (2017) illustrate the importance of auditing suppliers to drive conflict minerals out of supply chains. In the CDP database, many buyers' companies emphasize environmental performance. For example, many companies in the CDP data consider GHG emissions part of their balanced scorecard for supplier evaluation. Several firms such as Nestle are more likely to deselect suppliers for poor performance. Further, even if buyers are not directly or immediately using GHG emissions data in procurement decisions, the anticipation that buyers will do so will nevertheless motivate suppliers to continue reducing emissions.

Despite buyer firms' efforts at engagement, reductions in suppliers' GHG emissions are not guaranteed. It is likely that supplier non-cooperation could counteract buyers' efforts at engagement. In the case of monitoring, exclusive formal governance implies high ex-ante contractual costs and ex-post monitoring and enforcement costs (Huang et al. 2014). From a relational standpoint, exclusive use of formal contracts may also impact buyer-supplier cooperation, make the supplier more opportunistic, and decrease the efficacy of governance strategies (Dyer and Singh 1998). For example, Lee et al. (2012) and Plambeck et al. (2012) note that commoditization of auditing systems and widespread corruption has compromised the reliability of environmental standards. Similar arguments apply to the efficacy of firms pursuing knowledge sharing as well. Knowledge sharing as a form of informal governance requires an organization to share information and cultivate a strong relationship with suppliers. However, in the context of emission reductions, the pursuit of purely knowledge-related strategies may not be effective. The pursuit of knowledge strategies may engage suppliers, but may not systematically incentivize them to reduce emissions without monitoring. In line with this, large firms like Hyundai (Lee 2011), Walmart (Plambeck et al. 2012), and Apple have adopted comprehensive approaches to GHG reduction by not only working with suppliers on exchanging knowledge but also combining these measures with monitoring. Therefore, we hypothesize the following:

*H4: The pursuit of both knowledge and monitoring related governance mechanisms should assist in the reduction of greenhouse gases in the firm's supply base.*

### 3.3.2 On buyer firms' own emissions

Although the reduction of GHG emissions is the primary goal of governing suppliers, other benefits could accompany it. One such benefit would be a reduction in firms' own emissions. Through knowledge sharing, buyer firms learn for themselves the nuances of emission reduction. For example, Cassiman and Veugelers (2006) observe that effective R&D requires complementarity between the buyer's knowledge and supplier's knowledge. Importantly, buyer firms cannot measure what they do not know. Thus, for firms to institute measurement protocols, they must develop a basic understanding and awareness of the key elements of the GHG protocol. Blanco et al. (2016) found that firms discover new opportunities for improvement as they measure their carbon footprint more accurately and comprehensively, manifesting a learning-by-doing effect.

Finally, it is well established in supply chain literature that companies focus on collaborative knowledge sharing initiatives in order not just to help suppliers, but also to learn from them. For example, Toyota, Nissan, and Honda established supplier development programs and cultivated supplier loyalty in order to share knowledge from their supply network (Sako 2004). The establishment of knowledge sharing routines requires organizations to invest in the creation of teams that facilitate collaborative efforts (Dyer and Hatch 2004). These collaborative efforts also motivate suppliers to reciprocate since knowledge sharing from the focal firm is likely to motivate suppliers to share knowledge to facilitate the reduction of emissions. This is likely to hold true in the context of GHG emissions reduction. Accordingly, we hypothesize the following:

*H5: Pursuit of both knowledge and monitoring related governance mechanisms should result in greater emission reductions for the firm's own emissions.*

## 4. Model, data and measures

We use an amalgamation of multiple datasets including the Carbon Disclosure Project (CDP), Factset, Trucost and other external data sources including world bank. CDP data has been used by researchers for studying firms' own sustainability investment (Blanco et al. 2016), supplier's information sharing (Jira and Toffel 2013), Company's Scope 3 reporting quality (Craig et al. 2013) and shareholder value (Kim and Lyon 2011). However, no study that has used the CDP data has focused on the issue of drivers of supply base governance and its consequent emissions impact for buyers. The growing empirical research in this area has focused on examining governance strategies for emissions reduction using primarily qualitative methods (e.g., Formentini and Taticchi 2016, Villena 2018) or surveys of firms within a single industry in a country (e.g., Hoejmose et al. 2014, Gualandris and Kalchschmidt 2015). We cover a over 800) of the world's largest manufacturing companies in our analysis. Using textual responses that described the firm's governance strategy, we create a data dictionary to automate the coding of these unstructured responses using keywords and semantic rules (described later). Our final sample collated consisted of 1248 large public companies drawn from the CDP data, 12,831 unique suppliers and 36,838 pairs of buyer-supplier relationships from the FactSet database, integrated with GHG emissions drawn from TruCost database. The empirical analysis consists of two parts. We construct two sets of dependent variables corresponding to the two research questions focused on in this study. The first set of dependent variables (Stage 1) are the governance strategies, which are derived via text response from the CDP survey. The second set of dependent variables (Stage 2) is the GHG emissions data related to scope 1, scope 2 and supplier tier 1 data. We now describe the approach to generate the dependent variables related to governance strategies.

**4.1 Dependent variables: Stage 1 governance strategy**

To code governance strategies, we used the CDP survey Section 14-Scope 3 Emissions, question: "How do you engage your value chain to mitigate GHG emissions?" and a follow-up question that asks respondents to provide details of methods of engagement and strategy for prioritizing engagements and measures of success. Companies answer this survey question, and the derived follow-up questions to various levels of detail. Some responded with a few words and others wrote to the specified limit of 5000 characters. To code monitoring, we used an additional question "If you have data on your suppliers' GHG emissions and climate change strategies, please explain how you make use of that data." This question comes from CDP Survey Section 14.4C. We now introduce the coding strategy that we pursued in detail.

**4.2 Coding approach for knowledge sharing and monitoring**

We used a categorical variable to operationalize each of these strategies as present or absent. We process the answers using natural language processing (NLP) to determine if a firm pursued knowledge sharing, or monitoring, or both. NLP avoids subjective coding and has been increasingly used in several studies in the past (Ratner 2002). For example, in accounting and finance, content, readability, and sentiments from financial disclosure have been measured and linked to market reactions (Gentzkow et al. 2017, Loughran and McDonald 2016). In the Operations Management, textual analysis has been used to process user-generated content for product defect discovery (Abrahams et al. 2015) and studying sustainability reports (Higgins and Coffey 2016). We followed all the steps of content analysis detailed in Gentzkow et al. (2017). We performed data pre-processing to filter out common English running words provided by the NLTK package "Stopwords Corpus" (Bird et al. 2009). We then focused on domain-specific keywords related to knowledge sharing and monitoring practices (Supply Chain Governance) to design a code dictionary that combined domain-specific keywords with a combination of other words that have syntactic meaning. Syntactic parsing with domain-specific keyword examples can be found in medical field applications (Fan et al. 2013). Our decision of using a combination of words to identify syntactic meaning is consistent with many applications (for example, see Zhang et al. (2011)). Zhang et al. (2011) listed examples of existing methods including individual words, N-grams (character patterns), a set of individual words, multi-words and word sequences, and Ontology.

The specific details of the process are as follows: First, from the survey response text for each firm pertaining to the relevant question, we extract paragraphs that mentioned suppliers using keywords including supplier, vendor, or contractor. Second, if the paragraph had multiple sentences, we analyzed each sentence as a separate unit. Third, we determine if a sentence described a Knowledge Sharing behavior or a Monitoring behavior based on a word dictionary that was specifically constructed for each strategy using the process is described below.

We define knowledge sharing practice as one where a buyer firm provides training or technical support to suppliers to help them reduce GHG emissions. In the context of supply chain GHG emissions reduction, buyer firms share knowledge with suppliers in the form of workshops, supplier summits, and by helping suppliers to optimize production and logistic process. We process the responses to questions in the previous paragraph and generate a binary variable (Knowledge Sharing) to indicate if the answers to the questions detailed in §3.2 reveal any knowledge sharing practice being followed in the firm. For example, "we share best practices..." "suppliers come to the summit (in) which we presented" "assist suppliers (in creating) innovative solutions," all indicate knowledge sharing activity.

We compiled a list of knowledge sharing activities and developed a data dictionary to codify its implementation. The data dictionary contained keywords indicating actions (verb) and descriptions of the action (noun) (See Table 6). Our specific criteria for coding pursuit of knowledge sharing by a firm was that every sentence must contain at least one word from the Knowledge Sharing Word Dictionary's central keywords group (i.e., the verb group) and one from the Auxiliary Words group (i.e., the noun group). As seen in Table 6, the verb group includes words such as cooperate, share, show, etc. that occur in the "action" of Knowledge Sharing. Noun group includes words such as awareness, workshop, design, etc. that describe the "content or format" of Knowledge that has been shared.

--- Insert Table 6 here ---

We define monitoring as when a buyer firm uses supplier data in their scorecards and has a structured verification process for reducing GHG emissions. Monitoring forces suppliers to take initiatives to reduce and manage emissions targets. Companies that use supplier GHG emissions data in their scorecards and audit their suppliers are coded to pursue a Monitoring Strategy. Like knowledge sharing, we develop a data dictionary for monitoring consisting of central keywords (verb) and auxiliary words (noun) (see Table 7). As shown in Table 7, the central keywords are "audit" and "scorecard." For Audit, the auxiliary words capture the monitoring agency (third-party, etc.), content (energy efficiency, footprint, etc.), and/or location (mainly on-site). For scorecard, the auxiliary words focus on an attribute (e.g., energy efficiency) and approach (e.g., measure, progress, etc.). Regarding monitoring, firms that did not seek explicit data from suppliers were coded as those that did not monitor.

--- Insert Table 7 here ---

If a firm's answer contained multiple sentences that satisfy the requirements of one strategy, we only count its first appearance and not total occurrences. For example, "we share best practices." "suppliers come to the summit in which we presented …" "assist suppliers . . . innovative solutions" are all describing how buyer companies conduct knowledge sharing in order to help suppliers reduce GHG emissions. Coding these as Knowledge Sharing does not exclude this or other sentences that are coded as Monitoring, and vice-versa. A flow chart of the approach along with the questions used from the CDP survey is shown in Figure 1.

--- Insert Figure 1 here ---

**4.3 Empirical strategy: supplier governance strategy choices**

To examine the drivers of knowledge sharing and monitoring practices, we use a multinomial logit model. Multinomial logit is deemed as appropriate because firms' practices for knowledge sharing and monitoring are mapped into four categories: Only knowledge sharing, Only monitoring, both knowledge sharing and monitoring, and do Nothing. We designate do Nothing as the base category. The advantage of a multinomial logit model is that it allows for a categorical dependent variable, so we can analyze all 4 choices simultaneously. The multinomial logit model also has the flexibility to include independent variables that are continuous, ordinal or nominal and observe the impact of each variable individually. We employ the following specification.

$$P(y_i = s) = \frac{e^{\beta_s X_i}}{1 + \sum_{t \in S} e^{\beta_t X_i}} \tag{1}$$

Where

$$\beta_s X_i = \beta_s^0 + \beta_s^r RDIV_i + \beta_s^s SDIV_i + Controls_i \tag{2}$$

**4.4 Dependent variables: Impact on emissions**

Following a similar process as many previous studies (Dahlmann et al. 2017, Jira and Toffel 2013), we start with an intensity-based measure (total GHG emissions divided by annual revenue of a given firm) for GHG emissions, and calculate the yearly percentage change of emissions intensity using Trucost data. We assess the GHG emissions change on two levels: 1) Change on Buyer Firms' own emission (Scope 1 & Scope 2) and 2) Change on Buyer Firms' first Tier suppliers' emissions to account for the supply base. The yearly percentage change is calculated using the formula:

$$\delta_{i,t} = (\mathrm{ghg}_{i,t} - \mathrm{ghg}_{i,t-1})/\mathrm{ghg}_{i,t} \qquad (3)$$

Where $ghg_{i,t}$ denotes the GHG emissions associated with the firm $i$ at year $t$. The third subscript represents whether the variable measures the buyer firm's own emissions that of its first-tier suppliers.

$$\delta_{i,t,own} = (ghg_{i,t,own} - ghg_{i,t-1,\mathrm{own}})/ghg_{i,t,own} \qquad (4)$$

$$\delta_{i,t,suppliers} = (ghg_{i,t,suppliers} - ghg_{i,t-1,\mathrm{suppliers}})/ghg_{i,t,suppliers} \qquad (5)$$

and we take the median of the yearly change

$$\tilde{\delta}_{\mathrm{i,own,pre-2013}} = \{\delta_{\mathrm{1,own,2009}}, \delta_{\mathrm{1,own,2010}}, \delta_{\mathrm{1,own,}\widetilde{\mathrm{2011},}} \delta_{\mathrm{1,own,2012}}, \delta_{\mathrm{1,own,2013}}\} \qquad (6)$$

Our emissions data from TruCost is a panel data. Meanwhile, the CDP survey used is for the year 2013. To assess the impact of the governance practices, we split the GHG emissions panel data from TruCost into two halves: pre-2013 and post-2013. We calculate the Yearly Average GHG Emissions Percentage changes. For each company, we have two variables: percentage change in GHG before 2013 and the percentage change in GHG Change after 2013. We winsorize this variable (the percentage change in firms' total GHG emissions) at the top and bottom 5% to limit the impact of outliers. Our dependent variable details are depicted in Table 8.

--- Insert Table 8 here ---

**4.5 Impact of Governance Strategy**

To assess the impact of Governance strategies, we use matching methods. Consider a firm that did not pursue any strategies at the time of the CDP survey. We call $Y_0$ the outcome, where Y corresponds to the previously mentioned dependent variable - GHG emissions yearly percentage change or $gpc$ from 2014 to 2016. This is observed in our data set. We denote $Y_K$ as the potential outcome if the firm had pursued knowledge sharing strategy, $Y_M$ if the firm had pursued monitoring strategy, and $Y_B$ if the firm pursued both. We are interested in the mean of the differences, $Y_K - Y_0$, $Y_M - Y_0$, $Y_B - Y_0$, in other words, the average treatment effect. To estimate this, we cannot simply take the differences between the sample means for firms that pursue different strategies because covariates (e.g., firm financial resources, RDIV, SDIV, other covariates) can affect both the outcome of interest (GHG Emissions reductions) and the strategies they pursue, as discussed previously. Thus, a treatment effect framework is appropriate. We use matching methods to pair firms that do not pursue any strategy, and firms that pursue one out of the three possible strategy combinations (Knowledge Sharing, Monitoring, or Both). We include the same set of covariates as the multinomial logit model. In addition, we included the pre-2013 (CDP survey time) GHG emissions trend as a matching criterion to account for any prior changes in the emissions reduction trajectory in addition to other similar firm-level characteristics.

### 4.6 Independent Variables

We specifically focus on the effect of two key elements of supply base diversity. These are (a) diversity of industries, and (b) diversity of suppliers' geographical locations. To construct the supplier diversity measure for the independent variables we use the FactSet database for 2016. The supplier data was identified with the respective regions, sectors and the supplier's revenues were obtained from FactSet. FactSet was used due to its completeness (Gofman et al. 2018).

**Regional Diversity (RDIV)**: Consistent with the global nature of the overall supply chain, the suppliers in our dataset come from more than 100 nations. To measure the diversity in their location, we grouped them into the ten regional groups according to a scheme used by the United Nations (United Nations n.d.). For example, if a buyer has 2 suppliers, and one is from China and the second is from South Africa (from two different regions), this combination is different from having one supplier in Switzerland and another in Germany (both from Western Europe). Figure 2 shows the map we used to group countries into regions. To compute the regional diversity, we take a company's supplier list and find out the region to which each of its suppliers belongs. Let $g_{ij}$ be the count of company $i$'s supplier that belongs to geographic region $j$ , then $N_i = \sum g_{ij}$ is the total number of suppliers that buyer $i$ has across all regions j. The Herfindahl Index of Geographic Diversity is $HG_i = \sum \left(\frac{g_{ij}}{N_i}\right)^2$ for buyer $i$ and the diversity is the then calculated as $1 - HG_i$.

--- Insert Figure 2 here ---

**Sector Diversity (SDIV)**: Sector diversity is defined by the diversity in the industry composition of suppliers in the market. As in regional diversity, we capture the sector diversity using a Blau measure. We used the Industry Classification provided by FactSet. As before, if $N_i = \sum g_{is}$ is the total number of suppliers that belong to buyer i across all sectors. The Herfindahl Index of Supplier Industry Diversity is

$HG_i = \sum \left(\frac{g_{ij}}{N_i}\right)^2$ for buyer i and supplier diversity = 1 − Herfindahl.

### 4.7 Control variables

**Supplier count**: The number of suppliers is used as a control variable. This is necessary to control for the total number of suppliers within a firms' supply base.

**Kyoto protocol country**: Being in a Kyoto Annex I countries or in countries with high Environmental Performance scores (EPI Index) impacts firms' climate change information sharing decisions (Jira and Toffel 2013). Thus, the location provides motivation for buyer firms to invest in GHG reduction measures. GHG emissions regulations also foster an infrastructure of GHG emissions measure service providers and knowledge providers, hence lower the barrier for firms.

**Buyer sales**: To control for buyer size, we use the natural log of annual sales. Larger firms may have more resources that can allow better monitoring and knowledge sharing. We use sales in USD in 2013 to be consistent with the CDP survey time.

**Supplier sales**: To control for supply chain resources, we use the median supplier's sales among each focal firm's supply base. This helps in controlling for the firms' average level of resources among suppliers and accounts for the outliers among the supply base.

**R&D spending**: R&D Spending is the natural log of the annual average R&D spending of the focal firm. We control for the average R&D spending of the focal firm to account for specific technology investments that firms may have facilitating their ability to create knowledge in emission reduction efforts.

Overall, we combined multiple data sources on various levels. The illustration of our data processing is presented below in figure 3.

--- Insert Figure 3 here ---

## 5. Results

We now present the results of our analysis and hypotheses tests. In Tables 1 and 2, we present the descriptive statistics and correlation matrix for the independent and dependent variables. We find that the correlations are generally in the expected direction. For example, the correlation between RDIV and SDIV is positive and significant, 0.42. As seen in Table 1, firms that pursue different strategies have similar firm-level characteristics and supply base diversity. Firms that pursue no strategy are smaller as measured by buyer sales and have fewer suppliers, but the difference is not significant.

### 5.1 Strategy choice empirical results

We first present the results pertaining to the choice of governance strategies as estimated by the multinomial logit models. These results are presented in Table 3. We first focus on the direct effect of Regional Diversity (RDIV) and Sector Diversity (SDIV) on governance strategy choices. We find that increasing RDIV lowers buyers' propensity to adopt Monitoring strategy ($\beta m = -4.64$, $p = 0.06$). This suggests that when suppliers are dispersed across geographic regions, coordinating suppliers across different systems, creating and enforcing, audit standards internationally could be a daunting task for buyers. As shown in Table 3, a consistent negative coefficient associated with the monitoring strategy supports hypothesis H2a that a greater level of regional diversity is likely to reduce the likelihood of monitoring. In contrast to monitoring, regional differences promote knowledge sharing as seen in the positive coefficient of RDIV ($\beta = +3.71$, $p = 0.11$) although this is not statistically significant.

Focusing on sectoral diversity, increases in sectoral diversity have no significant direct effect on monitoring. It is interesting to note that the coefficient of sectoral diversity on monitoring is negative, albeit not significant. Further, the positive coefficient ($\beta = 3.72$, $p = 0.02$) of SDIV on knowledge sharing strategies is consistent with the idea that as firms have suppliers from a more diverse sectors, they are more likely to engage in knowledge sharing. This supports H2b. It is likely that both regional diversity and sectoral diversity of suppliers increase knowledge sharing. This could be attributed to the reduced challenges in implementing knowledge sharing strategies.

Focusing on the interaction between RDIV and SDIV, the multinomial logit model also revealed an interesting contrast in how SDIV and RDIV interact and impact monitoring and knowledge sharing in the supply base. Specifically, the coefficient of interaction between RDIV and SDIV (RDIV × SDIV) is positive ($\beta = 7.27$, $p = 0.05$) on Monitoring and negative on Knowledge Sharing ($\beta = -6.09$, $p = 0.08$). Finally, the coefficient of interaction between RDIV and SDIV (RDIV × SDIV) is positive on both knowledge sharing and monitoring ($\beta = 8.10$, $p = 0.09$). Recall that the direct effects of RDIV(SDIV) on monitoring (knowledge sharing) is negative (positive) and significant. Thus, the results suggest that the likelihood of monitoring (knowledge sharing) reduces with RDIV(SDIV) at higher levels of RDIV (SDIV). The possibility that both strategies are used increases with higher levels of RDIV and SDIV.

We plot the effects in Figure 4 – panels (a) through (d) to further illustrate the interactive roles of SDIV and RDIV on strategy choices. We use the estimated regression coefficient from the multinomial logit model in Table 3 to generate the predicted probability of implementing each governance strategy to generate plots in Figure 4. As seen in the margins plot, Figure 4(a) (4(c)) the predicted probability of adopting knowledge sharing reverses directions as the SDIV (RDIV) goes from low levels (mean− 1SD) to high levels (mean + 1SD). Specifically, the probability of pursuing Knowledge Sharing increases, when RDIV (SDIV) is low, and when SDIV (RDIV) increases from low levels to high levels. Similarly, Figure 4(b) (4(d)) shows marginal plots for the predicted probability of adopting monitoring at various levels of SDIV and RDIV. As seen in figures (4b) and (4d), the propensity of adopting Monitoring increases substantially when both SDIV and RDIV are high. Further, the propensity to adopt monitoring is high when the supply base has relatively lower levels of both SDIV and RDIV.

### 5.2 Emissions reduction

We now move to discuss the results of the impact of governance strategies on GHG emissions reduction. We first focus on the results of the impact of the pursuit of governance strategies on buyer firms' own emissions. Table 4 presents the GHG emissions intensity changes before and after 2013, the year of the CDP survey used in our data. In addition, we present results that used nearest neighbor matching (in column 1-3) and with propensity score matching (in column 4-6). Recall the variable definition from Section 3 where we focus on the yearly percentage change of GHG emissions as a measure of the impact of the independent variables. The results in Table 4 suggest that knowledge sharing is significantly and consistently associated with the reduction of buyer firms' own emissions followed by Monitoring. Specifically, knowledge sharing results in a 3% reduction in GHG emissions in 2014-2016 as compared to 2010-2013 (Table 4, Column 2). Further, monitoring results in a 3.8% reduction in GHG emissions in 2014-2016 as compared to 2010-2013 (Table 4, Column 3). When we examine firms that pursue both knowledge sharing and monitoring, while directionally consistent, results are insignificant. These could be a result of the smaller number of firms that implement both strategies contiguously.

We now focus on the results of GHG emissions reduction in Tier 1 suppliers. In Table 5, we present the results of changes in buyer firms' first-tier suppliers' GHG emissions. As seen in Table 5, we find a significant emissions reduction across all three types of strategies under the Nearest Neighbor Matching method: 1.3%, 1.3%, and 2.6 %. Monitoring is strongly associated with the reduction of buyer firms' first-tier suppliers' emissions. These results attest to the value of pursuing these governance strategies for reducing not only supplier emissions, but also own emissions, in line with H4 and H5.

## 6. Robustness checks

We performed several robustness checks to examine our results, listed below.

**Temporal change of supply base**: One data limitation in our analysis is the gap between when the CDP survey answers were collected and when the supply base diversity measures are computed. The former was obtained from the 2013 CDP survey while the later in 2017 via a snapshot for the supply base provided by FactSet data. Wu and Birge (2014) argued that the supply chain network structure is stable over a period of time. To examine the influence of using delayed supply base information, we also captured another snapshot of supply chain networks in 2018. We constructed the supplier diversity measures (SDIV, RDIV) for 2018 for the same firms in our data and compare them with 2017 measures. We found that although the actual buyer-supplier linkage underwent some changes, the diversity measures are significantly correlated at 0.67 for SDIV and 0.77 for RDIV. The plots are shown in

Appendix Figures 1a and 1b. Furthermore, the supplier median sales for the two timepoints were correlated at 0.61 as well indicating the suppliers were similar across the two timepoints. This is also plotted in Appendix Figure 1c.

**Coding methods robustness checks**: As described, we rely on coding unstructured data through the creation of word dictionaries to classify practices related to knowledge sharing and monitoring. Our automation approach minimizes the coding burden and that of judgment for coders. The dictionary was prepared after a thorough review of the literature, and by iteratively matching the dictionary with the text data. To ensure the method is robust, and the keywords used for coding are complete, we analyzed two types of errors: false-positive and false-negative. Since the set of coded examples is not very large (800 companies) we checked every positive instance to ensure that the strategies described are indeed the behaviors we would like to capture. To avoid false-negative from missing keywords and to prevent misclassification, we checked the high frequencies of words and n-grams. For this process, multiple members of the team manually checked the keywords dictionary in an iterative fashion and agreed on the keywords. This ensured that our data dictionary was robust and that the coding was manually verified.

**Alternative models and measures**: We also estimated alternative models to assess the robustness of results. For stage 1 results, we tested both alternative models and alternative measures of diversity. We use Biprobit estimation to model strategy choices under diversity drivers and found consistent results. The results are shown in Appendix - Table 2. Next, the correlation between control variables firm size and supplier number is high (0.72). To check if collinearity influenced the results, we estimate the model by dropping one of the two control variables at a time and found consistent results in Appendix – Table 1. These results show that the impact of both region and sector diversity on monitoring and knowledge sharing does not change.

To assess the robustness of stage 2 results, we tested both Nearest Neighbor Matching and Propensity Score Matching to pair up similar firms in order to measure the implications of governance strategies. We find consistent results. In addition to matching techniques, we use regression models as a robustness check and found directionally similar but larger effects. As seen in Appendix-Table 3, the coefficients related to both monitoring and knowledge sharing are significant and generally negative across all models. These support the results from the matching approaches.

## 7. Discussion and managerial implications

Engaging in emissions reduction is an important priority for firms. Prior literature has focused on how firms are using both formal and informal governance strategies to reduce emissions (Plambeck et al. 2012, Short et al. 2015). While firms continue to pursue both knowledge sharing and monitoring as approaches to govern the supply chains, when such approaches are implemented, and their relative efficacy has not been empirically investigated. Our study makes several important contributions.

First, firms need to engage the supply base to unlock the potential of emissions reduction, they also need a more rigorous understanding of both drivers of governance strategies and of their effectiveness. Specifically, we propose and investigate supply base complexities as drivers of governance strategies. We focus on (a) sector diversity (b) regional diversity, and (c) their interactions, an environment that signifies a high level of complexity. These two diversity measures are particularly important to understand since supply chains are increasingly becoming both more global in their spread across different regions of the world, and more specialized across different sectors. By combining financial and buyer-supplier relationship data we compute two diversity metrics, Regional and Sector diversity, and link them to companies' choice of strategies.

Our results suggest that firms prefer to monitor, particularly when both regional and sectoral diversity is high. Further, monitoring also appears to be a preferred choice when sectoral diversity is high, and regional diversity is low. In contrast, when regional diversity is high and sectoral diversity is low, knowledge sharing seems to be a preferred choice. Focusing on the economic impact, results pertaining to the antecedents of governance strategy choices suggest that as sectoral diversity increases by +1s.d, the chance of implementing monitoring (knowledge sharing) goes up by 54% to 93%.

Second, we show that interaction between these diverse elements has a differential impact on these strategies. Specifically, the chances of implementing both monitoring and knowledge sharing go up substantially as the firms find that their supply base increases in complexity in both the industries where the suppliers are coming from and the regions of sourcing.

Third, focusing on the impact of these strategies, our study not only examines their impact on supply chain partners but also within the firm. We find that firms can reduce their own emissions by both knowledge sharing and monitoring. In the supply chain literature, firms have placed a substantial value on collaboration as a key element of success (Dyer and Singh 1998, Heric and Singh 2010, Jap 1999). We find that collaboration helps both suppliers and the focal firm. Firms in this context can reduce up to an extra 3.8% emissions intensity within themselves, and 2.6% emissions intensity in their supply base via effective monitoring. In addition, firms can reduce 3% of their emissions, and 1.3% emissions among the supply base via knowledge sharing. These are substantial given that the Kyoto target is a 5.2% reduction worldwide (European Parliamentary Research Service 2015). Our results thus have important implications in presenting empirical evidence that such strategies are important to pursue.

Fourth, our findings also suggest that knowledge sharing is more effective in creating emission reduction outcomes as compared to monitoring, not only for the suppliers but also for the firm. This is an important insight that stresses the idea of "learning by governing." This is consistent with the finding in Blanco et al. (2016) that companies learn and improve through implementing emission reductions projects and Plambeck et al. (2012)'s case study that companies can profitably reduce emissions under direct and indirect control. This result also makes intuitive sense. When companies create supplier education programs to educate suppliers about the gravity of GHG emissions issue, or help them develop methods to cut emissions through better production process, product design or logistics, they first signaled their commitment to GHG emissions reduction and learned more about their own business in this process. Overall, our analysis suggests that by creating knowledge sharing approaches to better manage suppliers, firms also gain knowledge about their own operations.

Fifth, to analyze the governance strategy from company reports on a large scale, we developed coding methods using textual analysis. The rules of textual analysis were modified to account for the concept of supply chain governance strategy classification. Thus, the creation of a data dictionary to automate the coding of the different governance methods is an actionable outcome that other studies in this space, and the space of supply chain governance more generally, can use. This is useful since it is difficult to measure governance approaches using secondary data. We believe that creating such data dictionaries in the context of a supply chain can provide us valuable insights into the impact of governance strategies, it is clear that firms tend to pursue several methodologies and combination of multiple approaches. While manually coding them is nearly impossible, automated approaches, such as those applied in this study, can help us examine the rich data about collaboration much better.

**8. Limitations**

Our study also has a few limitations. We are limited to cross-sectional data in assessing firms' governance practices. Cross-sectional data on governance strategies limits us from making causality claims even though carbon emissions data come in panel data form. We tried to overcome this difficulty by using matching methods. However, such approaches also fall short of the quasi-experimental set up that would be ideal in establishing causality. In addition, our dataset limited us from making the claim that these observed GHG reductions in 2013-2016 are strictly linked to the governance strategies adopted by firms in 2013. Irrespective, if a fraction of firms that adopted governance strategies after 2013 were considered as non-acting in our data, our estimate would be a conservative estimate of the implications of GHG reduction strategies.

**References**

Abrahams, A.S., Fan, W., Wang, G.A., Zhang, Z. and Jiao, J., 2015. An integrated text analytic framework for product defect discovery. *Production and Operations Management*, *24*(6), pp.975-990.

Ahuja, G., 2000. Collaboration networks, structural holes, and innovation: A longitudinal study. Administrative science quarterly, 45(3), pp.425-455.

Amaral, L.A.N. and Uzzi, B., 2007. Complex systems—A new paradigm for the integrative study of management, physical, and technological systems. Management Science, 53(7), pp.1033-1035.
Anand, K. and Giraud-Carrier, F., 2016. Pollution Regulation: An Operations Perspective. Available at SSRN 2630315.
Apple Inc (2016) Supplier responsibility 2016 progress report. Retrieved at https://www.apple.com/supplier-responsibility/pdf/Apple_SR_2016_Progress_Report.pdf
Babich, V. and Tang, C.S., 2012. Managing opportunistic supplier product adulteration: Deferred payments, inspection, and combined mechanisms. Manufacturing & Service Operations Management, 14(2), pp.301-314.
Baldwin, Richard E., Global Supply Chains: Why They Emerged, Why They Matter, and Where They are Going (August 2012). CEPR Discussion Paper No. DP9103. Available at: https://ssrn.com/abstract=2153484
Batson, A., 2010. Not really 'made in China.'. Wall Street Journal, 10.
Bellamy, M.A., Dhanorkar, S. and Subramanian, R., 2019, July. Supply Chain Network Structure and Environmental Information Disclosure. In Academy of Management Proceedings (Vol. 2019, No. 1, p. 15728)
Bird, S., Klein, E. and Loper, E., 2009. Natural language processing with Python: analyzing text with the natural language toolkit. " O'Reilly Media, Inc.".
Blanco, C., Caro, F. and Corbett, C.J., 2016. The state of supply chain carbon footprinting: analysis of CDP disclosures by US firms. Journal of Cleaner Production, 135, pp.1189-1197..
Blanco, Christian, Felipe Caro, and Charles J. Corbett. "Operational Response to Climate Change: Do Profitable Carbon Abatement Opportunities Decrease Over Time?"
Bygrave, S.is and Ellis, J., 2003. Policies to reduce greenhouse gas emissions in industry: Successful approaches and lessons learned: workshop report. OECD.
Carbon Disclosure Project , 2017. Global Supply Chain Report 2017: Missing link: Harnessing the power of purchasing for a sustainable future. Carbon Disclosure Project, London.
Caro, F., Chintapalli, P., Rajaram, K. and Tang, C.S., 2018. Improving supplier compliance through joint and shared audits with collective penalty. Manufacturing & Service Operations Management, 20(2), pp.363-380.
Cassiman, B. and Veugelers, R., 2006. In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. Management Science, 52(1), pp.68-82..
Chen, L. and Lee, H.L., 2016. Sourcing under supplier responsibility risk: The effects of certification, audit, and contingency payment. Management Science, 63(9), pp.2795-2812.
Choi, T.Y. and Hong, Y., 2002. Unveiling the structure of supply networks: case studies in Honda, Acura, and DaimlerChrysler. Journal of Operations Management, 20(5), pp.469-493.
Craig, A.J., Blanco, E.E. and Caplice, C.G., 2013. Carbon Footprint of Supply Chains: A Scoping Study (No. NCFRP Project 36 (04)).
Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J. and Handfield, R.B., 2007. The severity of supply chain disruptions: design characteristics and mitigation capabilities. Decision Sciences, 38(1), pp.131-156.
Cummings, J.N., 2004. Work groups, structural diversity, and knowledge sharing in a global organization. Management Science, 50(3), pp.352-364..
Dahlmann, F., Branicki, L. and Brammer, S., 2017. 'Carrots for corporate sustainability': Impacts of incentive inclusiveness and variety on environmental performance. Business Strategy and the Environment, 26(8), pp.1110-1131.
Davis, S.J., Peters, G.P. and Caldeira, K., 2011. The supply chain of CO2 emissions. Proceedings of the National Academy of Sciences, 108(45), pp.18554-18559.
Dhanorkar, S., 2018. Environmental Benefits of Internet-Enabled C2C Closed-Loop Supply Chains: A Quasi-Experimental Study of Craigslist. Management Science, 65(2), pp.660-680.
Drake, D.F. and Spinler, S., 2013. OM forum—sustainable operations management: an enduring stream or a passing fancy?. Manufacturing & Service Operations Management, 15(4), pp.689-700.

Dyer, J.H. and Hatch, N.W., 2004. Using supplier networks to learn faster. MIT Sloan Management Review, 45(3), p.57.
Dyer, J.H. and Singh, H., 1998. The relational view: Cooperative strategy and sources of interorganizational competitive advantage. Academy of management review, 23(4), pp.660-679.
Environmental Protection Agency ,2010. Managing Supply Chain Greenhouse Gas Emissions: Lessons Learned for the Road Ahead. Washington, DC
Ernst, D., 2002. Global production networks and the changing geography of innovation systems. Implications for developing countries. Economics of innovation and new technology, 11(6), pp.497-523.
European Parliamentary Research Service, 2012. Doha Amendment to the Kyoto Protocol, viewed 31 October 2019, < http://www.europarl.europa.eu/EPRS/EPRS-AaG-559475-Doha-Agreement-Kyoto-Protocol-FINAL.pdf>
Fan, J.W., Yang, E.W., Jiang, M., Prasad, R., Loomis, R.M., Zisook, D.S., Denny, J.C., Xu, H. and Huang, Y., 2013. Syntactic parsing of clinical text: guideline and corpus development with handling ill-formed sentences. Journal of the American Medical Informatics Association, 20(6), pp.1168-1177.
Formentini, M. and Taticchi, P., 2016. Corporate sustainability approaches and governance mechanisms in sustainable supply chain management. Journal of Cleaner Production, 112, pp.1920-1933.
Gentzkow, M., Kelly, B. and Taddy, M., 2019. Text as data. Journal of Economic Literature, 57(3), pp.535-74.
Gofman, M., Segal, G. and Wu, Y., 2018. Production networks and stock returns: The role of vertical creative destruction. Available at SSRN 2981447.
Griffis E, Closs D , 2017. Managing the Complexity Paradigm, Supply Chain Management: Beyond the Horizon, Available at http://www.apics.org/docs/default-source/default-document-library/final-bth-msu-white-paper.pdf
Gualandris, J. and Kalchschmidt, M., 2016. Developing environmental and social performance: the role of suppliers' sustainability and buyer-supplier trust. International Journal of Production Research, 54(8), pp.2470-2486.
Guo, R., Lee, H.L. and Swinney, R., 2015. Responsible sourcing in supply chains. Management Science, 62(9), pp.2722-2744.
Hardcopf, R., Shah, R. and Mukherjee, U., 2019. Explaining Heterogeneity in Environmental Management Practice Adoption across Firms. Production and Operations Management.
Harland, C.M. and Knight, L.A., 2001. Supply network strategy: Role and competence requirements. International Journal of Operations & Production Management, 21(4), pp.476-489.
Heric, M. and Singh, B., 2010. Seizing the strategic high ground in capability sourcing. Bain & Company: Boston, MA, USA.
Higgins, C. and Coffey, B., 2016. Improving how sustainability reports drive change: a critical discourse analysis. Journal of Cleaner Production, 136, pp.18-29.
Hoejmose, S.U., Grosvold, J. and Millington, A., 2014. The effect of institutional pressure on cooperative and coercive 'green'supply chain practices. Journal of Purchasing and Supply Management, 20(4), pp.215-224.
Huang, M.C., Cheng, H.L. and Tseng, C.Y., 2014. Reexamining the direct and interactive effects of governance mechanisms upon buyer-supplier cooperative performance. Industrial Marketing Management, 43(4), pp.704-716..
Huckman, R.S. and Staats, B.R., 2011. Fluid tasks and fluid teams: The impact of diversity in experience and team familiarity on team performance. Manufacturing & Service Operations Management, 13(3), pp.310-328.
Jacobs, B.W., Singhal, V.R. and Subramanian, R., 2010. An empirical investigation of environmental performance and the market value of the firm. Journal of Operations Management, 28(5), pp.430-441.
Jacobs, B.W., 2014. Shareholder value effects of voluntary emissions reduction. Production and

Operations Management, 23(11), pp.1859-1874.
Jap, S.D., 1999. Pie-expansion efforts: Collaboration processes in buyer-supplier relationships. Journal of Marketing Research, 36(4), pp.461-475.
Jira, C. and Toffel, M.W., 2013. Engaging supply chains in climate change. Manufacturing & Service Operations Management, 15(4), pp.559-577.
Khuntia, J., Saldanha, T.J., Mithas, S. and Sambamurthy, V., 2018. Information technology and sustainability: Evidence from an emerging economy. Production and Operations Management, 27(4), pp.756-773.
Kim, E.H. and Lyon, T., 2011. When does institutional investor activism increase shareholder value?: the carbon disclosure project. The BE Journal of Economic Analysis & Policy, 11(1).
Kim, Y. and Worrell, E., 2002. International comparison of CO2 emission trends in the iron and steel industry. Energy policy, 30(10), pp.827-838.
Kleindorfer, P.R. and Snir, E.M., 2001. Environmental information in supply-chain design and coordination. Information Systems and the Environment, p.115.
Kraft, T., Valdés, L. and Zheng, Y., 2019. Motivating supplier social responsibility under incomplete visibility. Forthcoming in Manufacturing & Service Operations Management.
Kroes, J., Subramanian, R. and Subramanyam, R., 2012. Operational compliance levers, environmental performance, and firm performance under cap and trade regulation. Manufacturing & Service Operations Management, 14(2), pp.186-201.
Lee, D. and Bony, L.J., 2008. Cradle-to-cradle design at Herman Miller: moving toward environmental sustainability. HBS Case, (607-003).
Lee, H., Plambeck, E.L. and Yatsko, P., 2012. Embracing green in China--with an NGO nudge. Supply Chain Management Review, 16(2).
Lee, H.L. and Tang, C.S., 2017. Socially and environmentally responsible value chain innovations: New operations management research opportunities. Management Science, 64(3), pp.983-996.
Lee, K.H., 2011. Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry. Journal of cleaner production, 19(11), pp.1216-1223.
Loughran, T. and McDonald, B., 2016. Textual analysis in accounting and finance: A survey. Journal of Accounting Research, 54(4), pp.1187-1230.
Lu, G. and Shang, G., 2017. Impact of supply base structural complexity on financial performance: Roles of visible and not-so-visible characteristics. Journal of Operations Management, 53, pp.23-44.
Manuj, I. and Mentzer, J.T., 2008. Global supply chain risk management. Journal of business logistics, 29(1), pp.133-155.
Matthews, H. Scott, Chris T. Hendrickson, and Christopher L. Weber. "The importance of carbon footprint estimation boundaries, Environmental Science & Technology 2008 42 (16)
McDonough, W. and Braungart, M., 2002. Design for the triple top line: new tools for sustainable commerce. Corporate Environmental Strategy, 9(3), pp.251-258.
Miemczyk J, Johnsen TE, Macquet M (2012) Sustainable purchasing and supply management: a structured literature review of definitions and measures at the dyad, chain and network levels. Supply Chain Management: An International Journal 17(5):478–496.
Narayanan, S., Balasubramanian, S. and Swaminathan, J.M., 2009. A matter of balance: Specialization, task variety, and individual learning in a software maintenance environment. Management Science, 55(11), pp.1861-1876.
Organisation for Economic Co-operation and Development, 2014. Energy efficiency indicators: Essentials for Policy Making. OECD Publishing.
Plambeck, E., Lee, H.L. and Yatsko, P., 2012. Improving environmental performance in your Chinese supply chain. MIT Sloan Management Review, 53(2), p.43.
Plambeck, E.L. and Taylor, T.A., 2015. Supplier evasion of a buyer's audit: Implications for motivating supplier social and environmental responsibility. Manufacturing & Service Operations

Management, 18(2), pp.184-197.
Reid, E.M. and Toffel, M.W., 2009. Responding to public and private politics: Corporate disclosure of climate change strategies. Strategic Management Journal, 30(11), pp.1157-1178.
Ratner, C., 2002, September. Subjectivity and objectivity in qualitative methodology. Forum: Qualitative Social Research (Vol. 3, No. 3).
Sako, M., 2004. Supplier development at Honda, Nissan and Toyota: comparative case studies of organizational capability enhancement. Industrial and Corporate Change, 13(2), pp.281-308.
Short, J.L., Toffel, M.W. and Hugill, A.R., 2016. Monitoring global supply chains. Strategic Management Journal, 37(9), pp.1878-1897.
Tachizawa, E.M. and Wong, C.Y., 2015. The performance of green supply chain management governance mechanisms: A supply network and complexity perspective. Journal of Supply Chain Management, 51(3), pp.18-32.
Timmer, M.P., Erumban, A.A., Los, B., Stehrer, R. and De Vries, G.J., 2014. Slicing up global value chains. Journal of Economic Perspective, 28(2), pp.99-118.
United Nation, United Nations Regional Groups of Member States, Retrieved Jan 05, 2017 from https://www.un.org/Depts/DGACM/RegionalGroups.shtml
Villena, V.H., 2019. The Missing Link? The Strategic Role of Procurement in Building Sustainable Supply Networks. Production and Operations Management, 28(5), pp.1149-1172.
Wilding, R., Wagner, B., Pilbeam, C., Alvarez, G. and Wilson, H., 2012. The governance of supply networks: a systematic literature review. Supply Chain Management: An International Journal 17(4):358–376.
Williamson OE (1979) Transaction-cost economics: the governance of contractual relations. The Journal of Law and Economics 22(2):233–261.
Wu, J. and Birge, J.R., 2014. Supply chain network structure and firm returns. Available at SSRN 2385217.
Zhang, H., Aydin, G. and Heese, H.S., 2017. Curbing the usage of conflict minerals: A supply network perspective. Available at SSRN 2980369.
Zhang, W., Yoshida, T. and Tang, X., 2011. A comparative study of TF* IDF, LSI and multi-words for text classification. Expert Systems with Applications, 38(3), pp.2758-2765.

**Table 1 Summary statistics by strategy**

| | | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Nothing | RDIV | 0.50 | 0.25 | 0.00 | 0.88 |
| | SDIV | 0.60 | 0.19 | 0.00 | 0.86 |
| | Country EPI | 69.93 | 10.18 | 31.23 | 87.67 |
| | Kyoto Country | 0.55 | 0.50 | 0.00 | 1.00 |
| | Buyer Sales | 8.68 | 1.44 | 0.00 | 13.06 |
| | Supplier Sales | 6.70 | 1.22 | 2.97 | 11.68 |
| | Suppliers # | 2.24 | 1.34 | 0.00 | 5.83 |
| | Avg R&D | 2.30 | 2.75 | 0.00 | 9.19 |
| Monitoring | RDIV | 0.58 | 0.22 | 0.00 | 0.84 |
| | SDIV | 0.68 | 0.17 | 0.00 | 0.83 |
| | Country EPI | 69.97 | 9.62 | 31.23 | 87.67 |
| | Kyoto Country | 0.46 | 0.50 | 0.00 | 1.00 |
| | Buyer Sales | 9.46 | 1.19 | 7.48 | 12.31 |
| | Supplier Sales | 6.42 | 1.09 | 4.73 | 9.97 |
| | Suppliers # | 3.25 | 1.24 | 0.00 | 5.81 |
| | Avg R&D | 3.52 | 3.25 | 0.00 | 9.13 |
| Knowledge | RDIV | 0.55 | 0.25 | 0.00 | 0.86 |
| | SDIV | 0.66 | 0.12 | 0.23 | 0.86 |
| | Country EPI | 68.98 | 10.87 | 31.23 | 82.40 |
| | Kyoto Country | 0.50 | 0.50 | 0.00 | 1.00 |
| | Buyer Sales | 9.31 | 1.63 | 3.75 | 11.95 |
| | Supplier Sales | 6.54 | 1.11 | 4.11 | 9.94 |
| | Suppliers # | 2.87 | 1.51 | 0.00 | 5.80 |
| | Avg R&D | 2.78 | 3.17 | 0.00 | 8.92 |
| Both | RDIV | 0.62 | 0.21 | 0.00 | 0.86 |
| | SDIV | 0.63 | 0.21 | 0.00 | 0.80 |
| | Country EPI | 68.68 | 12.21 | 31.23 | 82.40 |
| | Kyoto Country | 0.43 | 0.51 | 0.00 | 1.00 |
| | Buyer Sales | 10.17 | 1.16 | 8.74 | 13.01 |
| | Supplier Sales | 6.39 | 1.42 | 4.31 | 9.90 |
| | Suppliers # | 3.59 | 1.31 | 1.39 | 5.71 |
| | Avg R&D | 1.43 | 2.94 | 0.00 | 8.60 |

**Table 2 Cross-correlation table**

| Variables | RDIV | SDIV | EPI | Kyoto | Buyer Sales | Spl Sales | Spl # | Avg R&D |
|---|---|---|---|---|---|---|---|---|
| RDIV | 1.00 | | | | | | | |
| SDIV | 0.42 | 1.00 | | | | | | |
| Country EPI | 0.09 | 0.01 | 1.00 | | | | | |
| Kyoto Country | 0.10 | -0.13 | 0.67 | 1.00 | | | | |
| Buyer Sales | 0.34 | 0.34 | 0.01 | -0.01 | 1.00 | | | |
| Supplier Sales | -0.12 | 0.01 | -0.11 | -0.08 | -0.11 | 1.00 | | |
| Suppliers # | 0.45 | 0.43 | -0.03 | -0.11 | 0.72 | -0.20 | 1.00 | |
| Avg R&D | 0.24 | 0.09 | 0.06 | 0.03 | 0.35 | -0.25 | 0.41 | 1.00 |

**Table 3 Results of the first stage multinomial logit regressions**

| | Controls Only | | | Full Model | | |
|---|---|---|---|---|---|---|
| | Monitoring b/p | Knowledge b/p | Both b/p | Monitoring b/p | Knowledge b/p | Both b/p |
| Country EPI Index | 0.02 | -0.01 | -0.01 | 0.01 | -0.01 | -0.01 |
| | (0.50) | (0.57) | (0.81) | (0.78) | (0.43) | (0.88) |
| Kyoto Country | -0.46 | -0.03 | -0.23 | -0.34 | 0.12 | -0.71 |
| | (0.25) | (0.92) | (0.76) | (0.39) | (0.73) | (0.37) |
| Buyer Sales | -0.00 | 0.18 | 0.51* | -0.06 | 0.18 | 0.55* |
| | (0.97) | (0.27) | (0.05) | (0.64) | (0.27) | (0.03) |
| Supplier Sales | -0.05 | -0.06 | -0.22 | -0.12 | -0.04 | -0.34 |
| | (0.70) | (0.61) | (0.61) | (0.42) | (0.70) | (0.34) |
| Suppliers Number | 0.48** | 0.21 | 0.47 | 0.41* | 0.18 | 0.43 |
| | (0.00) | (0.20) | (0.18) | (0.03) | (0.30) | (0.23) |
| Avg R&D Spending | 0.03 | -0.02 | -0.26* | 0.04 | -0.01 | -0.28* |
| | (0.60) | (0.62) | (0.02) | (0.49) | (0.83) | (0.01) |
| RDIV | | | | -4.64+ | 3.71 | -2.68 |
| | | | | (0.06) | (0.11) | (0.36) |
| SDIV | | | | -0.75 | 3.72* | -6.18*** |
| | | | | (0.67) | (0.02) | (0.00) |
| RDIV × SDIV | | | | 7.27* | -6.09+ | 8.10+ |
| | | | | (0.05) | (0.08) | (0.09) |
| constant | -4.97* | -3.86* | -7.72 | -2.96 | -5.95** | -4.96 |
| | (0.02) | (0.05) | (0.16) | (0.21) | (0.01) | (0.38) |
| BIC | 1179.728 | | | 1228.474 | | |

p-values in parentheses below the coefficient estimates; SDIV- Supplier Base Sector Diversity; RDIV - Supplier Base; Region Diversity; Buyer Sales is log value; Supplier Sales is log value of the sales of a median supplier; + p <0.10, * p<0.05, ** p<0.01, *** p<0.001

**Table 4 Impact of Strategies on Scope 1 & Scope 2 Emissions**

| | (1) NNM:Both b/p | (2) NNM:Knowledge b/p | (3) NNM:Monitor b/p | (4) PSM:Both b/p | (5) PSM:Knowledge b/p | (6) PSM:Monitor b/p |
|---|---|---|---|---|---|---|
| ATE | -.018 | -.03** | -.038** | -.0096 | -.03** | -.019 |
| | (0.20) | (0.00) | (0.00) | (0.57) | (0.00) | (0.30) |
| Observations | 886 | 935 | 912 | 886 | 935 | 912 |

Column 1-3 Use Nearest Neighbor Matching; Column 4-6 Use Propensity Score Matching;
**Variables used in matching**: all independent variables from stage 1 regression; the average reduction between 2010 to 2013 before the CDP survey

**Table 5 Impact of Strategies on 1st Tier Suppliers**

| | (1) NNM:Both b/p | (2) NNM:Knowledge b/p | (3) NNM:Monitor b/p | (4) PSM:Both b/p | (5) PSM:Knowledge b/p | (6) PSM:Monitor b/p |
|---|---|---|---|---|---|---|
| ATE | -.013+ | -.013+ | -.026*** | -.0028 | -.0027 | -.024* |
| | (0.05) | (0.06) | (0.00) | (0.68) | (0.73) | (0.01) |
| Observations | 886 | 935 | 912 | 886 | 935 | 912 |

Column 1-3 Use Nearest Neighbor Matching; Column 4-6 Use Propensity Score Matching; **Variables used in matching**: all independent variables from stage 1 regression; The average reduction between 2010 to 2013 before the CDP survey

**Table 6 Knowledge sharing coding rule**

| Central Keywords (Verb) | Auxiliary Words (Noun) |
|---|---|
| **COOP**: cooperate, collaborate, work with | **Direct Knowledge:** Awareness session, sustainability knowledge, sustainable design, workshop, manufacturing process, learning portal, seminar, webinar, best practice, technical support, technology, know-how |
| **SHOW & SHARE:** demonstrate, display, exhibit, present, showcase, share, exchange, interact, interchange | |
| **SUPPORT**: aid, assist, develop, encourage, guide, sponsor, subsidize, support, help | **Forums:** summit, forum |
| **TEACH**: instruct, learn, teach, tutor, educate, train | **Cost Reduction:** cost reduction, cost-saving |
| **INNOVATE**: create, innovate, co-create | **Innovation**: creation, innovative solution, new approach, new concept |

**Table 7 Monitoring coding rule**

| Central Keywords (Verb) | Auxiliary Words (Noun/Adjective) |
|---|---|
| **Audit** | **Third-party**: third party, $3^{rd}$ party, external, independent |
| | **Assessment**: assess, review, validate, quality, measure, metrics, certify, certification, evaluation |
| | **On-Site**: on site review, on site visit, on site audit, on site energy scan, evaluations |
| **Scorecard** | **Energy Efficiency**: energy use, footprint, emissions, data |
| | **Measure**: evaluate, metric, perform, track, review, progress, reward, incentive |

**Table 8 GHG Emissions Measure of Change**

| | ***Time*** | |
|---|---|---|
| **Scope** | Pre-2013 (Average between 2009 to 2013) | Post-2013(Average between 2013 to 2016) |
| Own | $\tilde{\delta}_{i,own,pre-2013}$ | $\tilde{\delta}_{i,own,post-2013}$ |
| Suppliers | $\tilde{\delta}_{i,suppliers,pre-2013}$ | $\tilde{\delta}_{i,suppliers,post-2013}$ |

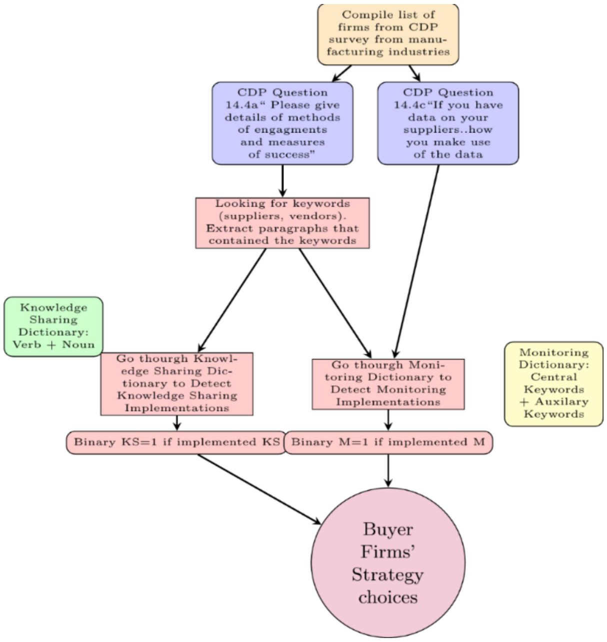



**Figure 1 Text processing flowchart**


**Figure 2 Regional groupings used for computing supplier regional diversity**

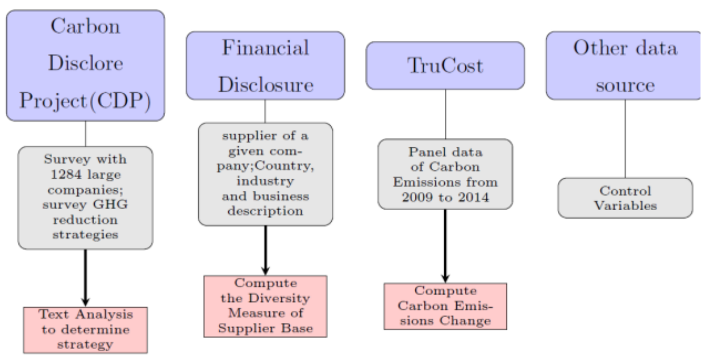
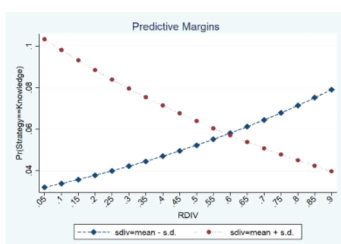
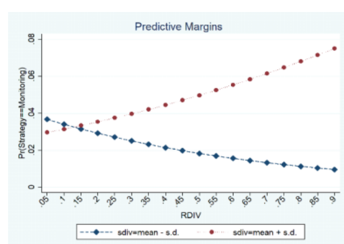


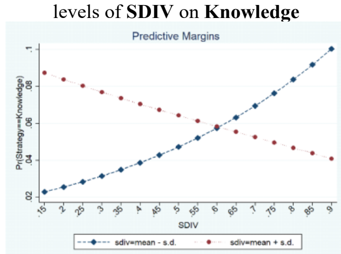

**Figure 3 Data processing**



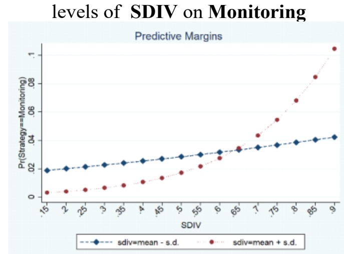

(a) Marginal Effect of **RDIV** at varying levels of **SDIV** on **Knowledge**




(b) Marginal Effect of **RDIV** at varying levels of **SDIV** on **Monitoring**




(c) Marginal Effect of **SDIV** at varying levels of **RDIV** on **Knowledge**




(d) Marginal Effect of **SDIV** at varying levels of **RDIV** on **Monitoring**

**Figure 4 Marginal Effect of Diversity on Strategy Choices**

**Appendices**

**Table 1 Robustness Checks Omitting High Correlation Terms**

| | (1) Strategy | | | (2) Strategy | | | (3) Strategy | | |
|---|---|---|---|---|---|---|---|---|---|
| | M | K | Both | M | K | Both | M | K | Both |
| | b/p | b/p | b/p | b/p | b/p | b/p | b/p | b/p | b/p |
| Country EPI Index | 0.00 | -0.02 | -0.02 | 0.01 | -0.02 | -0.01 | 0.01 | -0.01 | -0.01 |
| | (0.85) | (0.33) | (0.60) | (0.76) | (0.37) | (0.91) | (0.82) | (0.35) | (0.84) |
| Kyoto Country | -0.19 | 0.28 | -0.12 | -0.45 | 0.13 | -0.68 | -0.28 | 0.22 | -0.46 |
| | (0.65) | (0.44) | (0.87) | (0.26) | (0.72) | (0.44) | (0.48) | (0.52) | (0.55) |
| Buyer Sales | | | | 0.23* | 0.28* | 0.70* | | | |
| | | | | (0.02) | (0.01) | (0.00) | | | |
| Log(Buyer Asset) | -0.18 | 0.17 | 0.16 | | | | | | |
| | (0.27) | (0.26) | (0.46) | | | | | | |
| Supplier Sales | -0.23 | -0.05 | -0.38 | -0.24 | -0.09 | -0.24 | -0.18 | -0.06 | -0.21 |
| | (0.19) | (0.68) | (0.34) | (0.13) | (0.46) | (0.51) | (0.26) | (0.62) | (0.55) |
| RDIV | -5.70* | 3.09 | -6.45+ | -4.85* | 3.35 | -3.71 | -4.89* | 3.08 | -3.59 |
| | (0.03) | (0.17) | (0.08) | (0.04) | (0.15) | (0.29) | (0.04) | (0.18) | (0.29) |
| SDIV | -0.79 | 3.84* | -5.72* | -0.75 | 3.90* | -5.61* | -0.90 | 3.68* | -5.48* |
| | (0.64) | (0.01) | (0.01) | (0.68) | (0.02) | (0.00) | (0.60) | (0.02) | (0.01) |
| Suppliers Number | 0.62* | 0.16 | 0.61+ | | | | 0.43* | 0.31* | 0.67* |
| | (0.00) | (0.33) | (0.06) | | | | (0.00) | (0.01) | (0.01) |
| RDIV × SDIV | 8.13* | -5.49 | 12.44* | 8.23* | -5.41 | 9.35+ | 7.49* | -5.27 | 9.12+ |
| | (0.04) | (0.11) | (0.04) | (0.02) | (0.12) | (0.10) | (0.04) | (0.13) | (0.09) |
| constant | -1.32 | -5.61* | -1.19 | -3.87+ | -6.15* | -6.68 | -2.91 | -4.46* | -2.16 |
| | (0.64) | (0.01) | (0.84) | (0.09) | (0.00) | (0.27) | (0.17) | (0.00) | (0.64) |
| BIC | 1157.3 | | | 1188.4 | | | 1185.5 | | |

P values in parentheses below the coefficient estimates; SDIV- Supplier Base Sector Diversity; RDIV: Supplier Base Region Diversity; Buyer Asset is Log value of buyer firms' assets; Buyer Sales is log value. Supplier Sales is log value of the sales of a median supplier Model 1-Use Asset; Model 2 - Omit Supplier Numbers Model 3 - Omit Buyer Sales; + $p < 0.10$, * $p < 0.05$

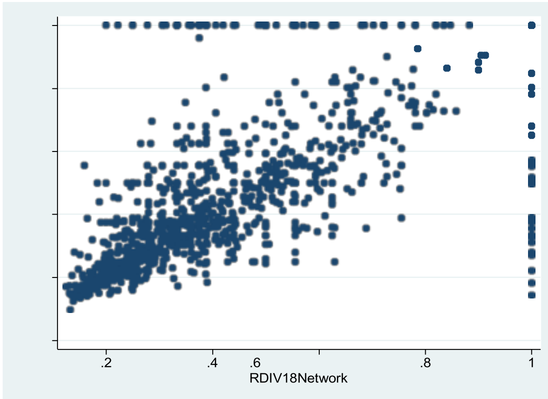
**Table 2 Robustness with bi-probit model**

| | M | K |
|---|---|---|
| | b/p | b/p |
| Country EPI Index | 0.00 | -0.01 |
| | (0.78) | (0.49) |
| Kyoto Country | -0.16 | 0.02 |
| | (0.34) | (0.91) |
| Buyer Sales | 0.02 | 0.11 |
| | (0.70) | (0.13) |
| Log(Buyer Asset) | -0.08 | -0.03 |
| | (0.19) | (0.52) |
| Supplier Sales | -2.09* | 0.57 |
| | (0.02) | (0.49) |
| RDIV | -0.79 | 0.67 |
| | (0.19) | (0.27) |
| SDIV | 0.21* | 0.11 |
| | (0.01) | (0.13) |
| Suppliers Number | 3.47* | -1.05 |
| | (0.01) | (0.41) |
| RDIV × SDIV | -0.01 | -0.03 |
| | (0.53) | (0.20) |
| constant | -1.58+ | -2.46* |
| | (0.09) | (0.01) |
| BIC | 1166.1 | |

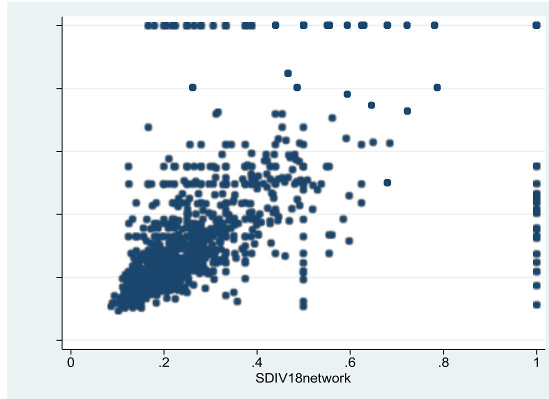
+ $p<0.10$, * $p<0.05$ for both Table 2 and Table 3

**Table 3 Robustness Checks 2nd Stage Impact Measure with Regression**

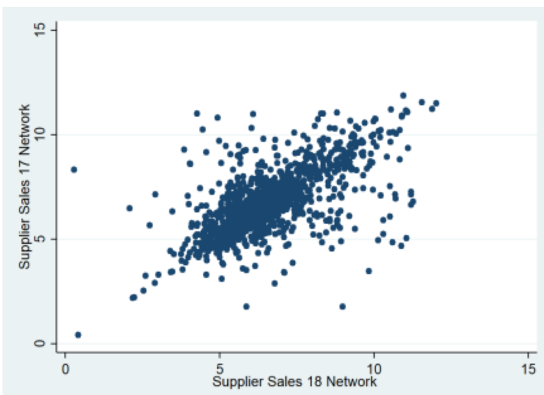
| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | b/p | b/p | b/p | b/p | b/p | b/p |
| Country EPI Index | | -0.00* | | -0.00* | | -0.00* |
| | | 0.00 | | 0.03 | | 0.02 |
| Kyoto Country | | 0.04* | | 0.01 | | 0.03* |
| | | 0.00 | | 0.11 | | 0.00 |
| Buyer Sales | | 0.01 | | 0.01* | | 0.00 |
| | | 0.14 | | 0.01 | | 0.44 |
| Supplier Sales | | 0.01* | | 0.00 | | 0.00 |
| | | 0.01 | | 0.81 | | 0.53 |
| Suppliers Number | | -0.01 | | -0.01* | | -0.00 |
| | | 0.22 | | 0.02 | | 0.33 |
| Avg R&D Spending | | -0.00 | | 0.00 | | -0.00+ |
| | | 0.19 | | 0.30 | | 0.07 |
| RDIV | | 0.03 | | 0.01 | | 0.01 |
| | | 0.15 | | 0.49 | | 0.50 |
| SDIV | | -0.11* | | -0.04* | | -0.05* |
| | | 0.01 | | 0.03 | | 0.01 |
| Monitoring | -0.05* | -0.03* | -0.04* | -0.03* | -0.04* | -0.03* |
| | 0.00 | 0.05 | 0.00 | 0.01 | 0.00 | 0.02 |
| Knowledge | -0.04* | -0.03* | -0.02 | -0.01 | -0.03* | -0.02* |
| | 0.01 | 0.02 | 0.13 | 0.17 | 0.01 | 0.01 |
| Both | -0.03 | -0.02 | 0.00 | 0.01 | -0.00 | 0.00 |
| | 0.35 | 0.45 | 0.83 | 0.73 | 1.00 | 0.92 |
| Scope 1&2 Reduction (own) | 0.27* | 0.25* | | | | |
| | 0.00 | 0.00 | | | | |
| First Tier Supplier Reduction | | | 0.20* | 0.20* | | |
| | | | 0.00 | 0.00 | | |
| Scope 1&2 & First Tier Supplier Reduction | | | | | 0.30* | 0.29* |
| | | | | | 0.00 | 0.00 |
| constant | 0.04* | 0.12 | 0.01* | 0.02 | 0.03* | 0.10+ |
| | 0.00 | 0.10 | 0.00 | 0.56 | 0.00 | 0.08 |
| BIC | -918.9 | -915.2 | -2013.6 | -1983.6 | -1716.4 | -1692.1 |




RDIV contrasting 17 and 18 networks




SDIV contrasting 17 and 18 networks




Supplier Median Sales contrasting 17 and 18 networks

**Figure 1 Correlation of Diversity Measures and Suppliers Sales captured in two different time period**