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Greenhouse Gas Emissions and Supply Chain Leakage

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ABSTRACT
Consumer awareness and government regulation have increased pressures for firms to engage in reducing greenhouse gas (GHG) emissions. However, emissions reduction efforts within a firm could create a supply chain leakage effect—higher emissions in the supply chain. This research studies the supply chain leakage effect of GHG emissions reduction, and examines the environmental and financial impact of this effect. Our results suggest that a higher level of supply chain emissions is associated with the adoption of emissions reduction programs by the firm, and that this supply chain leakage contributes to the firm's financial performance.

Keywords: GHG emissions, Scope 3 emissions, environmental management, supply chain leakage, empirical analysis

1. Introduction

The annual greenhouse gas (GHG) emissions across the globe continue to rise and are projected to increase 43 percent by 2035 (EIA 2010). Concurrently, consumer awareness of climate change and GHG emissions create mounting pressures on firms to curb emissions (Hoffman 2005). The reactions from firms, however, have been slow to generate meaningful results, often because of the costly resources required to reduce emissions. Nevertheless, firms have implemented a variety of innovative initiatives to improve internal processes, introduce new products and technology, or acquire emissions credits to reduce GHG emissions (Krass, Nedorezov and Ovchinnikov 2013; Stern 2010; Oberholzer-Gee, Reinhardt and Raabe 2007; Kolk and Pinkse 2005). Implementing such initiatives often leads firms to engage with their supply chains partners to accommodate process and product innovations such that "activities and sources of high emissions can be carried out elsewhere in the supply chain." (Kolk and Pinkse 2005, p.10). We define this effect as a *leakage effect* in the supply chain which is a change in supply chain emissions associated with an emissions reduction initiative by a focal firm. This is analogous, at a firm level, to "carbon leakage", where emissions are moved from high pressure countries to countries with lower expectations and standards of GHG emissions (Babiker 2005). Literature on GHG emissions has focused on firm decisions and performance, with mixed findings (Jacobs 2014; Kroes, Subramanian and Subramanyam 2012; Plambeck 2012). In this study, we focus on supply chain emissions and examine the leakage effect of firms' emissions reduction programs. Further, we investigate the financial implications of supply chain leakage to better understand the motivation behind such behavior.

The rising awareness of GHG emissions has led firms to reformulate strategies toward climate change (Reid and Toffel 2009). First movers, such as WalMart, have quickly announced highly publicized programs, such as energy efficiency and "zero" waste, to improve processes and adopt technologies for carbon abatement. This market dynamic has created competitive pressure for others to follow suit and establish their own emissions reduction programs (Plambeck and Denend 2007). In addition, similar pressure is being exerted through increasing governmental regulations. For instance, the Environmental Protection Agency (EPA) began to regulate GHG emissions under the "Clean Air Act" in 2011. Major initiatives, such as the Carbon Disclosure Project (CDP) and the Global Reporting Initiative (GRI), have also been launched to improve GHG visibility and encourage emissions reduction activities. Yet, "while a growing percentage of companies responding to the 2015 questionnaire have set reduction targets — 44 percent in 2015, compared to 27 percent in 2010 — those companies' emissions actually increased over the same period of time"(Rosen 2016). In the long term, while GHG emissions can only be reduced through improvements in processes and technologies (Kolk and Pinkse 2005), there is a long lag between the invention and full-scale adoption of clean technologies (Rau, Toker and Howard 2010). As an alternative, firms can also offset their emissions by investing in projects that provide emissions reduction elsewhere; but some offset projects, such as overseas community-focused projects, are often too costly (Carbon 2006; Harris 2007). Seeking short-term and less costly solutions, high emissions firms may instead involve their supply chains to expand feasible options, possibly leading to supply chain leakages.

The supply chain leakage effect may be amplified by firms' increasing focus on supply chain development and strategic supply chain relationships. Apple, Inc., for instance, has a sophisticated supply chain that is highly outsourced and offshored based on cost efficiency, market access, and technological strategies. The top 200 suppliers include large manufacturers such as 3M, Qualcomm, and Intel, and small niche companies such as NXP Semiconductor, many of which are overseas companies. The interdependency of supply chain activities and the corresponding GHG emissions create opportunities for Apply to take advantage of the leakage effect, that is, Apple's emissions can be moved to its complex supply chains in connection with its outsourcing strategies. As another example, Boeing, a large, U.S.-based manufacturer in the transportation industry moved its high-emissions paint operations to Asia. This company, which commits to high environmental standards, had a major paint operation that substantially constrained the capacity of the facility and carried significant environmental concerns. Capacity expansion would have led to greater paint usage rates and greater emissions, requiring expensive and time-consuming permitting processes. These concerns persisted until the opportunity arose to move the paint operations, and therefore the emissions, to a new, downstream organization in Asia where managing paint emissions would be less costly[1]. The above examples suggest that companies might "subcontract certain high-emission activities and thus reduce their own emissions while increasing those of their partners" (Kolk and Pinkse 2005, p.10). Furthermore, the leakage effect may be a beneficial result of technological advances in green product and production designs. For example, Tesla Motors designs and produces a highly environmentally friendly Model S with an electric motor, resulting in four times lower CO_2 per mile than an equivalent gas-powered car. Electricity for the lithium battery comes from power plants in the supply chain that may have high GHG emissions (Wade 2016), but also allow for centralized control and carbon capture. Such examples highlight how the goal of emissions reduction can influence the re-distribution of emitting activities in the supply chain.

Recent efforts have made significant advances in understanding firm decisions and outcomes in emissions (Kroes, Subramanian and Subramanyam 2012; Fu, Kalkanci and

[1] The interview results can be provided upon request.

Subramanian 2017; Muthulingam, Corbett, Benartzi and Oppenheim 2013; Marquis, Toffel and Zhou 2016; Reid and Toffel 2009; Blanco, Caro and Corbett 2016). Literature mostly focuses on a firm's own emissions and its financial impact (Flammer 2015), with supply chain impact largely overlooked. The few exceptions indicate that supply chains can play an important role in emissions reductions. In particular, it has been shown that supplier disclosure of information related to climate change depends on the buyers (Jira and Toffel 2013), and collaboration in the supply chain induces joint effort in reducing emissions (Caro, Corbett, Tan and Zuidwijk 2013; Klasson and Vachon 2003). However, none have focused on the leakage effect. Supply chain leakage is also related to a spillover effect that occurs in various supply chain contexts. For instance, spillovers occur in product innovation when firms integrate their suppliers (Petersen, Handfield and Ragatz 2005), in productivity through supply chain interactions and structures (Serpa and Krishnan 2017), and in learning associated with supply chain collaboration (Dong and Dresner 2012). More recent research indicates that knowledge spillovers of quality in the supply chain are conditional on whether efforts to improve quality are focused on supplier activities (Muthulingam and Agrawal 2016). Yet, supply chain spillovers in sustainability have not been studied, particularly in the context of supply chain leakage of GHG emissions. Because evaluating the impact of individual firms' emissions on performance may be incomplete when substantial leakage exists in the supply chain, identifying and understanding such a leakage effect makes a significant contribution to the literature of sustainable operations management. To address the literature gap, we take a supply chain perspective to examine the relationship among a firm's GHG emissions reduction initiatives, its supply chain emissions, and firm financial performance.

Specifically, we propose to address the following research questions: First, *does a firm's emissions reduction program generate emissions leakage to its supply chain?* Second*, does the leakage effect benefit the firm financially?*

To investigate our research questions, we analyze data developed from the Bloomberg Environmental Social and Governance (ESG) and Compustat databases. We focus on the environmental impact that a firm's emissions reduction programs has on supply chain-level emissions (i.e., Scope 3 emissions), as well as the impact of emissions on financial performance. Public attention has mostly been given to a firm's internal emissions, i.e., Scope 1 and Scope 2 emissions, while neglecting the supply chain emissions, i.e., Scope 3 emissions. Scope 1 Emissions are emissions from sources that are owned or controlled by the reporting company, for example, through combustion of fossil fuels in companies' daily operations. Scope 2 Emissions are emissions that are a consequence of the activities of the reporting company, but that occur at sources owned or controlled by another entity. This usually refers to the carbon emissions generated out of the energy purchased by focal firms. Scope 3 emissions cover a firm's indirect emissions from its supply chain activities, which include emissions generated from both upstream and downstream supply chain activities (Source: Bloomberg ESG). Carbon emissions, for example, generated at a firm's logistic provider or a production supplier are included in the firm's Scope 3 emissions. We provide a detailed discussion about our data and their characteristics and usage in the empirical setting section. Moreover, we examine the total supply chain effect of a firm's emissions reduction programs. By doing so, we provide a broader view of a firm's emissions reduction effects, to include both the firm's and its supply chain's emissions, given the leakage effect. In addition, we extend our analysis to explore the roles of market competition in supply chain leakage because a firm's green image can be a strategic advantage. This extension allows for a closer examination of the market pressure as a driver for emissions reduction efforts. We further extend our analysis to investigate regulatory and market heterogeneity in domestic vs. global markets. The result may help confirm the role of the regulatory environment in firms' emissions reduction efforts.

We find that, first, a firm's emissions reduction program is indeed accompanied by an increase in the firm's Scope 3 emissions, i.e., emissions created from a firm's supply chain activities. This leakage is a negative externality that may neutralize the firm's emissions reduction effort. Second, we find that while firm-level GHG emissions are negatively associated with the firm's financial performance, its supply chain emissions, or Scope 3, can be positively related to firm financial performance. This finding also suggests that the strategic and economic motivations for the leakage effect may extend beyond cost efficiencies for the focal firm, although the result shows that the firm can benefit from reducing its own GHG emissions. Third, our extended findings suggest that emissions reduction programs may be positively associated with the total supply chain emissions, i.e., the combination of the firm's and its supply chain's emissions. This indicates that supply chain leakage may offset the firm's own environmental benefits from its emissions reduction efforts. Fourth, we find that competition intensity and stricter regulations both lead to a stronger supply chain leakage effect, implying that the pressure for firms to lower emissions without increasing costs can exacerbate the leakage effect. Both results confirm that market and regulatory intensities serve as incentives for emission reduction efforts and subsequent supply chain leakage.

This research contributes to the sustainable operations literature as follows. First, by empirically establishing a supply chain leakage effect from firms' emissions reduction efforts, we expand the scope of sustainability research on GHG emissions to supply chains. Understanding the impact of GHG emissions reduction beyond a focal firm is important because supply chain activities, and the respective emissions they generate, are connected across supply chain members. Overlooking the interactions between supply chain members may lead to underestimating supply chain emissions in an effort to reduce internal emissions by a firm. This may adversely affect the firm in the long term only when supply chains are sufficiently visible with a large number of firms disclosing their supply chain emissions information (Blanco, Caro and Corbett 2016). Yet our study shows that supply chain leakage may be positively associated with firm financial performance, which explains why firms may be slow to reduce supply chain emissions. The combined results provide insight in understanding firm incentives with regards to supply chain emissions reduction and in developing strategies and public policies for sustainable supply chain management, which we will discuss in detail in the discussion section. Last but not least, the extension of the main results shows that the total supply chain emissions are dominated by the leakage effect, indicating that focusing on internal emissions of a firm can be misleading in assessing supply chain emissions. The leakage effect is also greater under more intense competition and greater regulatory threats, supporting the arguments that firms engage in emissions reductions and their supply chains under the pressure from the marketplace and government regulations.

The remainder of the paper is organized as follows. Section 2 provides a brief review of the industry background, followed by a discussion of hypotheses. The empirical setting and data are described in Section 3. The analysis and results are provided in Section 4. We conclude with a discussion of our findings and contributions in Section 5.

2. Supply Chain Emissions: Background and Hypotheses

In this section, we describe an example of firm level emissions reduction efforts and supply chain emissions as background to our theoretical propositions. We then develop hypotheses to address our main research questions based on the relevant practices and related literature.

2.1. Emissions reduction in the supply chain: The case of Apple Inc.

To better understand the processes of emissions reduction and potential leakage in the supply chain, we examine the case of Apple Inc., one of the leading companies in promoting corporate environmental responsibility. Since 2006, Apple has launched a number of programs with a focus on energy efficiency. In recent years, the company has engaged in powering global operations with 100 percent renewable energy and has implemented new clean energy programs in emerging markets to promote low-carbon manufacturing. Apples states that it has reduced carbon emissions per product by 30% since 2011 (Apple 2017).

Apple’s statements have been met with skepticism, however. Greenpeace, one of the leading NGOs in environmental protection, has challenged these claims (Greenpeace 2012), and a recent investigation of Apple’s emissions reduction shows that “between 2010 and 2014, Apple's annual carbon emissions grew by 131 percent, with an average increase of 25 percent per year”, and the increase mostly “comes from huge jumps in emissions stemming from manufacturing and transportation of products.” At a product level, Apple emitted 69.1 kilogram of CO_2 from its manufacturing and transportation in 2010, which grew to 92.9 and 95.6 kilograms in 2011 and 2013, respectively (Cole 2015). In fact, Apple states in the company's annual Environmental Responsibility reports that, for instance, “the carbon emissions we reported for 2013 are 9 percent higher than the carbon emissions we reported for 2012” and “from 2013 to 2014, there was a 5 percent increase in manufacturing emissions attributed to the production needs” (Apple 2014; Apple 2015).

Our own calculations, based on public sources, also confirm these emissions patterns — Apple’s total emissions have decreased over the years, but the manufacturing emissions have grown in the same period of time (both controlling for Apple’s revenue growth) (see Figure 1). Apple has long outsourced manufacturing, logistics, transportation and final assembly, and in 2011, it further outsourced sub-assemblies and test of finished products (Apple 2011). Further, by 2017, Apple has contracted out all of the recycling work (usually accounting for 1%-2% of Apple’s total emissions) to third-party providers, such as SIMs recycling solutions (Koebler 2017).

[Insert **Figure 1** about Here]

Upstream in Apple’s supply chain, Advanced Semiconductor Engineering (ASE), a top 200 supplier for Apple, has been a long-time, stable partner with Apple. ASE is the world's biggest chip assembler and tester based in Taiwan, and Apple is ASE's biggest customer, contributing 31.2% of the company's revenue of $8.73 billion in 2015 (Cheng 2016). Figure 2 depicts ASE’s total emissions intensity from 2010 to 2015, and shows a steady growth of emissions intensity from 2010 to 2012 and a continuous growth from 2014 to 2015. According to the corporate social responsibility reports of ASE, the increase in emissions intensity is likely due to capacity expansion of the existing plants as well as incorporation of new production sites, an indication of an increase in their operations.

[Insert **Figure 2** about Here]

Combining the GHG emissions patterns of Apple and ASE over this time period, we observe decreasing emissions levels at Apple and increasing emissions levels in Apple’s supply chain, where most of Apple’s GHG emitting activities have been outsourced. This example shows how a focus on environmental responsibility may be concomitant with a distribution of activities in the supply chain that changes where GHG emissions occur. Specifically, carbon footprint reduction in some areas at the expense of others suggests a need to consider the relationship between emissions reduction efforts and the potential supply chain leakage.

2.2. Literature and Hypotheses

Empirical research on the relationship between a firm’s emissions reduction effort and its environmental performance has been limited, with most research focusing on the financial impacts of firm environmental performance (Flammer 2015). We draw from the broad literature in the areas of emissions reduction, sustainability, and supply chain management to develop our hypotheses.

The majority of research has taken a firm-centric view on firm environmental management. For instance, Kroes, Subramanian and Subramanyam (2012) examine the impact of different levers firms can employ to comply with environmental regulations on their environmental performance. Similarly, Fu, Kalkanci and Subramanian (2017) study the effect of hazardous substance ranking on firm emissions reduction efforts. Muthulingam, Corbett, Benartzi and Oppenheim (2013) find that the sequence of how energy-saving recommendations are presented to companies affects their adoption rates. Marquis, Toffel and Zhou (2016) study the firm behavior of selective disclosure in environmental management and suggest that environmentally-damaging firms are less likely to engage in such behavior. As well, the firm-centric view is dominant in research under the context of greenhouse gas emissions reduction. For example, Reid and Toffel (2009) find that both stakeholder influences and state regulations could spur changes in firm behaviors to reduce carbon emissions, while Blanco, Caro and Corbett (2016) suggest that carbon emissions reduction efforts should be viewed as opportunities for continuous improvement as opposed to a one-time affair.

Such stream of research is limited because a firm's environmental responsibility also covers its supply chain partners (Sodhi 2015). There are exceptions however. For instance, Plambeck (2012) shows how Wal-Mart works with suppliers to reduce GHG emissions in its supply chains. Jira and Toffel (2013) examine disclosure of climate change-related information by suppliers and find that how buyers use such information is important, as are the industries and countries of suppliers. Klasson and Vachon (2003) indicate that supply chain collaboration may affect a firm's level of engagement in pollution prevention (Klassen and Vachon 2003), while Caro, Corbett, Tan and Zuidwijk (2013) suggest that GHG emissions are the result of joint effort and hence a methodology of double-counting can help induce optimal emissions reduction efforts. Other research also indicates that increasing pressures to promote environmental activities drives firms to shift their polluting activities to other parties located overseas (Korten 2015; Surroca, Tribó and Zahra 2013). Lee, Klassen, Furlan and Vinelli (2014) suggest that significant changes in firm environmental requirements can generate uncertain leakage upstream in the supply chain. Thus, literature increasingly is interested in the supply chain implications of environmental efforts. Our study extends this literature by first examining the effects a firm's GHG emissions reduction efforts have on supply chain leakage and, subsequently, on financial performance.

Our first hypothesis proposes how supply chain emissions, i.e., scope 3 emissions, may increase when firms commit to emissions reduction programs. Firms rationalize the set of business activities performed by themselves versus their supply chains. Such rationalizing is based on both the firm's capabilities in such activities and the associated costs of performing these activities (Argyres and Zenger 2012). Activities deemed unfavorable given such rationalizing become candidates for transferring outside the firm and to the supply chain. The Apple example described above shows how, strategically, Apple has positioned itself away from manufacturing because of its core focus on design and marketing, given the superior manufacturing capabilities and cost efficiencies of ASE and others. To maintain operational and financial performance, firms regularly redistribute such business activities in the supply chain.

When rationalizing emissions-related activities, firms are pressured by environmentally conscious stakeholders, market competition, and government regulation. Competing in markets with increasing societal awareness of climate change, firms must establish their emissions reduction initiatives to conform to the stakeholder pressures from various groups, such as the consumer market, governmental regulators, business partners, local communities and NGOs (Deutsch 2007). To customers and markets, the growing environmental consciousness of consumers, with more accessible and observable emissions information, affects firm brand building and brand recognition (Straughan and Roberts 1999). Intense competition in the market heightens the pressure on firms to initiate emissions reduction programs as a component of their competitive strategies (Delmas and Toffel 2008; Delmas and Toffel 2010). Moreover, as governmental attention to carbon emissions becomes more likely, firms with emissions reduction goals may see the need to move toward future compliance to avoid potential penalties and costs (Reid and Toffel 2009). In addition, NGOs as stakeholders will scrutinize firms promoting a "green" image as was the case with Greenpeace's approach toward Apple. The CDP has similarly obtained emissions data and published reports of firm emissions performance. Third-party organizations such as the Electronic Industry Citizenship Coalition (EICC) audit companies' emissions efforts to check for accountability.

When firms commit to reducing their GHG emissions through initiatives and programs, they often need to allocate a variety of costly resources to the effort, often with changes in operations processes and strategies. Specifically, firms may need to invest in environmentally-friendly raw materials, redesign products, technologies, and operations, and commit to continuous monitoring of operational processes, worker training, and environmental auditing (Kroes, Subramanian and Subramanyam 2012). Yet, such efforts may be too costly to implement and sustain (Kroes, Subramanian and Subramanyam 2012; Palmer, Oates and Portney 1995; Walley and Whitehead 1994). In addition, many innovations in green technologies may take years before being ready for adoption at a large scale and in a cost-efficient manner (Rau, Toker and Howard 2010). In a shorter term, firms may not have the necessary capabilities and technologies to achieve GHG emissions goals. This was the case with Boeing where other supply chain partners had superior capabilities in their paint operations.

As a result of rationalizing emissions-related business activities under the constraints of cost, technology, and capacity, firms may find opportunities to transfer some of the emitting activities to supply chain partners that may either have lower costs or higher capabilities with managing GHG emissions. These opportunities are also less risky because of the supply chain's lower visibility and less scrutiny from stakeholders. It is particularly the case with increasingly more complex supply chains, where a major corporation may have thousands of suppliers and customers, many of which may locate in other regions with lower environmental requirements (Ghemawat 2011; Surroca, Tribó and Zahra 2013). Doing so enhances the firm' environmentally friendly reputation that can be demonstrated to stakeholders while achieving cost advantages at the same time (Rose 2007; Scherer and Palazzo 2008; Witt and Lewin 2007). This process is analogous to the "pollution haven hypothesis" where firms outsource polluting activities to regions where supplier visibility and stakeholder expectations are low (Copeland and Taylor 2004; Madsen 2009).

Finally, technological advances may alter existing rationalization outcomes of emissions-related activities, and require redistribution of corresponding emissions along the supply chain. Specifically, product and technology innovations to address emissions issues are supported by new materials and advanced technological capabilities. Sourcing for new materials and adjusting for the new capacities will have a direct impact on the supply chain. As in the Tesla example, where battery energy is more capable of reducing local emissions than the gas-powered energy from a car engine, the supply chain party that handles the battery manufacturing may witness an increasing level of carbon emissions. Process improvements may also require a reallocation of activities along the supply chain (Kolk and Pinkse 2005), leading to a higher level of supply chain emissions. Facanha and Horvath (2005) examine an automobile manufacturer and find that while outsourcing logistics to 3PLs may increase 3PL emissions, the total life cycle environmental impact for the automobile decreases due to better fleet efficiencies. As a result, the Scope 3 emissions, which represent the emissions from a firm's supply chain activities, may increase in association with the firm's commitment to emissions reduction, as shown in the adoption of an emissions reduction program. This is the supply chain leakage effect resulting from firm efforts to improve emissions performance and conform to stakeholder expectations. Hence, we hypothesize:

H1: A firm's emissions reduction programs are positively associated with its Scope 3 emissions.

While the leakage effect can be motivated by firms' searching for a more efficient supply chain solution for emissions reduction, its financial outcome is unknown. Previous research has investigated whether "it pays to be green", but the potential economic benefits of environmental performance are mixed. A positive relationship between environmental performance and firm financial performance has been reported by Hart and Ahuja (1996), Klassen and McLaughlin (1996), King and Lenox (2001) and Jacobs (2014). Ortiz-de-Mandojana and Bansal (2015) find a positive association between firm environmental practices and long-term benefits, such as improved financial volatility and sales growth, but fail to find significant short-term financial benefits. In the context of emissions in particular, researchers find that firm-level emissions reduction can have both a positive and negative impact on firm financial performance (Jacobs 2014; Kroes, Subramanian and Subramanyam 2012). One perspective is that emissions reduction can be divergent from corporate core strategies and may spur negative market reactions (Fisher-Vanden and Thorburn 2011; Kroes, Subramanian and Subramanyam 2012; Walley and Whitehead 1994). For instance, reducing emissions may require allocation of scarce corporate resources at the expense of shareholders, especially when these resources are more costly and do not contribute directly to the corporate value proposition (Jacobs, Singhal and Subramanian 2010). Specifically, the allocation of resources would reduce efficiency, and therefore the value, of the firm, leading to negative reactions from the stock market. However, the majority of the studies in the related literature find that firms benefit financially from their internal emissions reduction (Plambeck 2012{Plambeck, 2007 #1863)}. Using CDP data from 2006 to 2008, Matsumura, Prakash and Vera-Muñoz (2013) find that for every additional thousand metric tons of carbon emissions disclosed by firms, firm value decreases by $212,000 on average. Better environmental performance, such as a lower emissions level, could help firms improve market reputation to appeal to an environmentally conscious public, and strengthen positive perceptions among stakeholders (Plambeck 2012). Strong market appeal and stakeholder appreciation will improve firm financial performance. In addition, investing in emissions reduction may eventually reduce waste and increase energy efficiency, as new and advanced environmentally friendly technologies may also be cost and energy efficient and reliable, which further reduces risks of liabilities(Jacobs 2014; Porter and Van der Linde 1995). The above firm level findings are in parallel to the arguments for the leakage effect at the supply chain level. The increase in supply chain emissions, as a leakage of a firm’s emissions reduction effort, can be a result of the firm’s taking advantage of the positive perception among stakeholders while avoiding the costs of the effort. The financial outcome, therefore, should be favorable to the firm.

However, if the supply chain leakage only “transfers” emissions to the supply chain, the firm does not necessarily benefit from the leakage effect. This is particularly the case when the emissions reduction costs are not significantly lower in the supply chain because a higher supply chain cost in emissions reduction will come back to the firm. There are two possibilities, however, where the firm may benefit from the leakage—higher cost efficiency in the supply chain, in terms of emissions reduction, and high tolerance of emissions in the supply chain. The former leads to Pareto improvement in terms of both GHG emissions and financial performance; the latter, however, simply moves the emissions to a less visible place, where higher emissions are not noticed. The case with higher supply chain efficiency in emissions reduction is similar to outsourcing. Outsourcing the firm’s high-emissions activities to its supply chain allows firms to take advantage of the lower costs and decreased visibility of the supply chain, improving the firm’s financial performance.

In the case where emissions are only shifted to the supply chain, the higher tolerance level of emissions in the supply chain makes it possible to reduce emissions reduction costs. Suppliers may be better equipped with advanced clean technologies and are more capable of absorbing the costs associated with emissions, maintaining high levels of GHG emissions can be justifiable financially (Kostova, Roth and Dacin 2008). A combination of low costs and high emissions in the supply chain may therefore benefit the firm financially. This combination has been commonly observed and discussed in the context of emerging markets offshoring, where firms can take advantage of loose environmental regulations and low costs in the emerging markets (Reinaud 2008). However, firms, regardless of where they are in the supply chain, are often reluctant to reduce emissions because of the concerns over the emissions-cost tradeoff.

For suppliers in the upstream supply chain, for example, serious concerns over costs may also be prevalent. For example, “of 2,363 suppliers surveyed, only 29 percent are experiencing emissions savings year over year” (ClimateWire 2013). Hence, reducing supply chain emissions will be costly to supply chain members too, which may raise prices for purchased goods as well as distribution costs, affecting focal firm performance.

Yet the association between a firm’s Scope 3 emissions and firm financial performance has been largely overlooked in the literature. With an increasing awareness of supply chain environmental management and the availability of supply chain level data, it has become more important and feasible to evaluate the financial impact of supply chain emissions. We hence propose that a firm’s Scope 3 emissions may have a positive relationship with the firm’s financial performance.

H2: A firm’s level of Scope 3 emissions is positively associated with firm financial performance.

3. Empirical Setting and Data

3.1. Data Source

This section describes our data and collection method. The empirical literature in emissions is primarily based on data collected as a part of the CDP, an international organization based in the U.K. that focuses on collecting and disclosing information on GHG emissions of major corporations since year 2000 (Jira and Toffel 2013, Reid and Toffel 2008). Similar information has also been collected and made available via Bloomberg and other data providers such as Thompson Reuter. In this research, we develop our sample from Bloomberg’s ESG data, which is an established data channel that generates 718 million data hits per month with more than 20,000 regular users (CDP 2015). All GHG emissions data from Bloomberg have source documentation connected to company reports where published information is extracted to ensure validity and traceability. Bloomberg ESG data also contain emissions measures provided by the CDP, which allows for a cross check between the two sources. Annual data for the period of 2006-2015 were extracted from Bloomberg and matched to firms’ financial performance from the Compustat database. The final sample is an unbalanced panel dataset of 1,043 firm-year observations for 242 unique firms in 20 industry segments (based on 2-digit NAICS codes).

The emissions data collected by Bloomberg and the CDP follow the GHG Protocol developed by The World Business Council (WRI), whose Greenhouse Gas Protocol is considered an authoritative source of emissions reporting standards and has been widely used by a range of industries. While the CDP sends out a questionnaire to firms each year to collect information on firm emissions, Bloomberg relies on multiple data sources, such as annual reports, firm 10-Ks, Corporate Responsibility or Sustainability reports, website releases, GRI indexes, and definitive proxy statements (i.e., DEF 14A).[2] Comparing emissions variables, e.g., Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions, between the two data sources, however, shows an insignificant statistical difference.[3]

Prior literature indicates that the CDP data of Scope 3 emissions may have reporting issues (Blanco, Caro and Corbett 2016), and these issues may also exist in Bloomberg as the sources of these two datasets may be the same. For instance, companies such as Merck, Co. and BP, often use CDP survey results on GHG emissions in annual reports as part of “Corporate Sustainability”, which is one of the sources that Bloomberg relies on to collect firm emissions information.

To better understand the reporting of Scope 3 emissions, we further conducted interviews with a few major companies and found that firms, such as those in the computer industry, are fairly confident in their Scope 1 and 2 emissions reporting, but may be uncertain

[2] Bloomberg ESG Team, email exchanges with Morgan Tarrant (BLOOMBERG/ 120 PARK) mtarrant2@bloomberg.net as of Feb. 17, Feb. 29, and Mar. 28, 2016.

[3] Details of the analysis can be provided upon request.

about the Scope 3 emissions because data availability at suppliers may be limited. Suppliers may not fully understand or possess proper techniques to accurately measure their emissions, or may be unwilling to share information with firms due to confidentiality concerns.[4] It appears that a lack of supply chain visibility and the distance at which supply chain carbon emissions are measured may be the main sources for the potential reporting issues (Busch 2010; Busch 2011; Hoffman and Busch 2008). However, while accuracy, methodology, scope, and methods in reporting GHG emissions can vary from firm to firm and from year to year, the process required by the GHG Protocol should minimize systematic manipulation of the emissions information. According to Matsumura, Prakash and Vera-Muñoz (2013),

> "the markets can assess the credibility of the firm reporting data in the CDP by comparing them to similar data from other firms in the same industry, and some of the data may be assured. Further, although responding to the CDP questionnaire is voluntary, once a firm decides to participate, it is significantly more likely to participate in the future. These repeated interactions between the CDP and the firm will generally increase the cost of reporting untruthfully, particularly as more firms in the industry decide to report and assurance of emissions becomes more widespread. Untruthful reporting that is eventually revealed can damage the firm's overall reporting credibility and expose it to litigation risk (p. 701)."

In addition, the CDP has leveraged institutional investors to encourage firms to better disclose their Scope 3 emissions (Blanco, Caro and Corbett 2016; Kolk, Levy and Pinkse 2008). The number of companies reporting Scope 3 emissions has increased to nearly 70% by 2015 (CDP 2015), and third parties are often involved in the data collection process for neutrality. In both the CDP and Bloomberg data, the emissions measures are calculated carefully and often audited by or even outsourced to third party specialists. For example, the electronics industry has been working with the EICC to audit supplier sustainability performance with shared data. This provides a safeguard to the quality and consistency of emissions reporting in the supply chain. In addition, the reporting issues can also be adequately addressed with a sample that has a reasonable coverage of firms and time (Moorhead and Nixon 2014).

Nonetheless, such reporting issues raise concerns of measurement issues, also known as errors-in-variables (EIV), for Scope 3 from the CDP data and likely the Bloomberg data. Linear classical EIV can be corrected as a special case of endogeneity (Chen, Hong and Nekipelov 2011; Hausman 2001), and we address this by treating emissions variables as endogenous variables and estimating our models with instruments (Chen, Hong and Nekipelov 2011; Hausman 2001). To further address potential reporting issues, we provide a discussion on the treatment and impact of supply chain information disclosure in the section on *Robustness Tests*, as well as a discussion on a sub-sample analysis using more recent year data to account for the ambiguity and learning curve of firms in reporting Scope 3.

3.2. Econometric Model and Variable Description

We test our hypotheses by constructing the following econometric models. First, we develop our main model to connect Scope 3 emissions to emissions reduction programs based on our first hypothesis; second, we examine the relationship between Scope 3 and firm financial performance. The first model is formulated as follows.

$$SCOPE\_3_{it} = \alpha_0 + \alpha_1 ER_{it} + \boldsymbol{\alpha}_2 \boldsymbol{W}_{it} + \boldsymbol{\alpha}_3 \boldsymbol{I}_i + \epsilon_{it} \quad (1)$$

In Equation (1), Scope 3 emissions ($SCOPE\_3_{it}$) are formally defined as "all non-Scope 2, indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting company,

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[4] This statement is based on our interviews with one of the major electronic product companies. The interview document is available upon request.

electricity-related activities (e.g. transmission & distribution losses) not covered in Scope 2, outsourced activities, waste disposal, and etc." (Source: Bloomberg ESG). In essence, $SCOPE\_3_{it}$ captures indirect emissions of firm *i* in year *t*, related to supply chain activities. Emissions reduction program (ER_{it}) is a dummy variable indicating whether the company has set GHG emissions targets, or has disclosed any goal to reduce GHG emissions via any initiatives in its annual reporting period, with 1 (0) representing yes (no). These initiatives may include use of alternative energy-efficient fuels, reduction of electricity use, redesign of product and operations technology aimed at minimizing emissions, and worker training and environmental auditing (Source: Bloomberg ESG). For example, according to Exxon Mobil's annual report, "the Environmental and Energy Savings Initiative (EESI) is part of Exxon Mobil's ongoing commitment to increase energy efficiency and reduce our overall environmental footprint." In this case, ER_{it} would be coded "1" for Exxon Mobil in the reporting period[5]. While we present the model with a simple binary variable for emissions reduction, we also estimate models with a continuous variable, i.e., cumulative emissions reduction effect (CER_{it}), that is calculated by following the method used in Muthulingam and Agrawal (2016). Specifically, we define $CER_{it} = \sum_{t=1}^{t} er_{it}$, where er_{it} is the number of emissions reduction initiatives at firm *i* in year *t*. Specifically, we consider the following five initiatives as part of firms' GHG emissions reduction efforts: energy efficiency (whether the company has disclosed any efforts in making use of its energy more efficiently), product emissions efficiency (whether the company has developed and/or launched products in the reporting period to address future impacts of climate change), green building (whether the company has disclosed using environmental technologies and/or environmental principles in the design and construction of its buildings), sustainable packaging (whether the company has taken any steps to make its packaging more environmentally friendly), and environmental management systems (whether the company has introduced any kind of environmental management system to help reduce the environmental footprint of its operations). In a given year, a company can have from 1 to 5 of these initiatives coded as 1, otherwise 0. And the measure, CER_{it}, represents the cumulative effect of firms' emissions reduction programs during the sample period. Both ER_{it} and CER_{it} are collected from Bloomberg ESG and are used in the estimation of Equation (1) and presented together.

We include major control variables to account for firm-level heterogeneity ($\boldsymbol{W}_{it}$). Specifically, Total Firm Assets (*ASSETS*) is a control variable for firm size (Dowell, Hart and Yeung 2000; King and Lenox 2002; Kroes, Subramanian and Subramanyam 2012; Vachon and Klassen 2008). Other things being equal, large firms likely have a higher level of emissions, both internally and externally, due to the size of their operations. Capital Intensity (*CAPITAL_INTENSITY*) is also a control variable, calculated by dividing capital expenditures by sales (King and Lenox 2001). Because capital investments improve efficiencies in facilities and information systems, high capital intensity indicates operational efficiency (Gaur, Fisher and Raman 2005). High capital intensity encourages firms to carry out production and distribution activities, as well as emissions abatement efforts, instead of involving the supply chain in such activities. It is, therefore, expected that capital-intensive firms may have a lower level of emissions in the supply chain. Energy consumption (*ENERGY*) includes energy directly consumed by a firm "through combustion in owned or controlled boilers, furnaces, vehicles, or through chemical production in owned or controlled process equipment" (Bloomberg ESG). Higher energy and electricity use by a firm may also indicate emissions-intense supply chain activities. This is because industrial emissions can be decomposed into scale, composition, and technology, all of which are usually shared by supply chain members with respect to energy use. Therefore, a higher level of energy use by a firm may need a greater scale of supply chain support, leading to higher Scope 3 emissions. Plant and equipment (*PPE*) represents the scale

[5] Bloomberg ESG Team, email exchanges with Madison England (BLOOMBERG/ 120 PARK) mbrown612@bloomberg.net as of Mar. 6, 2017.

and scope of a firm's facilities and the costs associated with them. A higher level of *PPE* may be linked to more GHG emitting facilities and activities that also extend to supply chains. In addition, industry plays an important role in Scope 3 reporting, as for example, more than 80% of the emissions come from supply chains for firms in the information technology industry, while this number is less than 10% for firms operating in the utilities industry (CDP 2017). Hence, we include $\boldsymbol{I}_i$, as industry dummies to control for industry heterogeneity. Table 1 summarizes all variable definitions and Table 2 summarizes all variable statistics.

To examine the relationships between firms' GHG emissions and their financial performance in Hypothesis 2, we formulate the following equation:

$$ROA_{it} = \beta_0 + \beta_1 TOTAL_{it-1} + \beta_2 SCOPE\_3_{it-1} + \boldsymbol{\beta}_3 \boldsymbol{Z}_{it} + \omega_i + \delta_t + \varepsilon_{it} \quad (2)$$

To be consistent with previous research, we use return on assets (ROA_{it}) as the dependent variable for firm financial performance, calculated as the ratio between firm net income and total assets (Hart and Ahuja 1996) and collected from the Compustat database. Our main independent variables in Equation (2) include the total internal GHG emissions ($TOTAL_{it-1}$) and Scope 3 emissions ($SCOPE\_3_{it-1}$) of firm *i*. The total internal GHG emissions is defined as "the combination of Scope 1 and Scope 2 emissions; Scope 1 Emissions are emissions from sources that are owned or controlled by the reporting company, and Scope 2 Emissions are emissions that are a consequence of the activities of the reporting company, but that occur at sources owned or controlled by another entity" (Source: Bloomberg ESG). We expect a negative relationship between a firm's total internal GHG emissions and its ROA, as prior literature predominantly argues that better firm environmental performance will be positively associated with firm financial value (Jacobs, Subramanian, Hora and Singhal 2017; Matsumura, Prakash and Vera-Muñoz 2013; Plambeck 2012). In addition, we expect a positive relationship between a firm's Scope 3 emissions and its financial performance, as proposed in Hypothesis 2.

Prior literature indicates that the realization of "bottom line" benefits for companies depends on the time lagged emissions reduction efforts. This is because the cost savings or revenue generation from emissions reduction outcomes may take time to realize. (Hart and Ahuja 1996; White, Becker and Savage 1993). We use one-year lagged total internal GHG emissions and one-year lagged Scope 3 emissions in the model (Clarkson, Li, Richardson and Vasvari 2011; Hart and Ahuja 1996). In Equation (2), $\boldsymbol{Z}_{it}$ is a vector of control variables (*ASSETS*, *CAPITAL_INTENSITY*, and *LEVERAGE*). In line with King and Lenox (2002) and Kroes, Subramanian and Subramanyam (2012), we control for firm size, which is measured by firm total assets (*ASSETS*). Capital intensity (*CAPITAL_INTENSITY*) is expected to affect firm performance as capital-intensive firms possess capital assets such as plants, factories and equipment that may be expensive and may require long periods of use to produce an adequate return on investment (Miller and Cardinal 1994). Leverage (*LEVERAGE*) is also a control in equation (2), which represents firm debt burden, an indicator of firm financial performance. We define *LEVERAGE* as the ratio of debt to total firm assets (Barnett and Salomon 2012; Capon, Farley and Hoenig 1990; McConnell and Servaes 1995). Last but not least, ω_i denotes firm dummies and δ_t denotes year dummies to control for fixed firm and fixed year effect.

All of the continuous variables are log transformed, except for ratio-type variables.

[Insert **Table 1 and 2** about Here]

3.3. Analysis

Given the industry and time heterogeneity of Scope 3 emissions reporting, we first estimate Equation (1) using feasible generalized least square method (FGLS), which is specified for panel specific autocorrelation, AR(1), and heteroscedasticity (Kros, et al 2012, Greene 2003). FGLS-based estimation allows for accurate and powerful inferences in settings that are subject to clustering problems and autocorrelation problems (Hansen 2007). Given the heterogeneity in Scope 3 emissions across industries and over time (Blanco, Caro and Corbett 2016), this is an appropriate estimation method. Specifically, the specification of panel-specific autocorrelation allows us to capture changes in Scope 3 emissions by individual firms across time. In addition, we include industry dummies to detect industry heterogeneity in Scope 3. While the literature has supported the use of FGLS in such settings (Kroes, Subramanian and Subramanyam 2012), we also estimate an alternative model with firm and time fixed effects. Specifically, we estimate Equation (1) using a fixed effect model with Driscoll and Kraay standard errors. Such estimation also allows for controlling for cross-sectional dependence that may occur in our data (Hoechle 2007). We report the FGLS results as our main result while discussing the fixed effects results as robustness checks. Another issue that may affect our model specification and estimation is the potential endogeneity of ER in association with Scope 3. However, the adoption of ER, which focuses on a firm's internal emissions reduction, is mostly driven by customer and NGO pressures and governmental regulations (Kolk and Pinkse 2005), and is unlikely to be caused by a firm's supply chain emissions. And our use of both ER, a dummy variable that is based on a broad coverage of emissions reduction programs, and CER, a continuous variable, in our main model, should help minimize the concern over the endogeneity between ER and Scope 3 emissions. A Hausman test based on the lagged CER as an instrument is not significant.

As indicated earlier, the measurement of Scope 3 emissions may consist of EIV, which can be treated as an endogeneity issue using instruments (Bound, Brown and Mathiowetz 2001; Carroll, Ruppert, Stefanski and Crainiceanu 2006; Chen, Hong and Nekipelov 2011; Hausman 2001; Meijer and Wansbeek 2000). We therefore employ a two-stage instrumental variable (IV) regression to estimate Equation (2). Although the reporting issue of Scope 1 and 2 is less of a concern, we suggest that a firm's internal emissions (both 1 and 2) may be endogenous with the firm's financial performance. As discussed earlier, a firm's environmental performance may bring financial value to the firms as a positive signal to the market. Financially-well-off firms may have better motivations and likely more pressures to pursue emissions reduction, possibly leading to a better internal emissions performance. Hence, we also treat the firm's total internal GHG emissions as an endogenous variable in our model.

The first stage model is similar to Equation (1), with added instruments. We estimate a fixed effect model to account for unobserved firm-specific heterogeneity. Industry heterogeneity clearly exists in our sample: the top three industries represented by the firms are manufacturing (39%), finance and insurance (20%), and information (11%). Table 3 lists all the industries in the sample. Given the unequal presence of industries and their corresponding measurement complexities of Scope 3 emissions, industry level control is necessary beyond the treatment of firm-specific heterogeneity in our analysis. As such, we cluster by industry in our main model estimations based on 2-digit NAICS codes. In addition to industry heterogeneity, Scope 3 emissions vary by time as firms learn to better collect emissions information across years (Blanco, Caro and Corbett 2016). We therefore include year dummies in our two-stage model.

[Insert **Table 3** about Here]

The ideal instrumental variables should be highly correlated with Scope 3 emissions and/or total internal GHG emissions, while not correlated with firm ROA. The following three instrumental variables are selected and collected from public sources: industry-level scope 3 intensity, industry-level total internal emissions intensity, and renewable energy consumption rankings. Similar to Dowell, Hart and Yeung (2000), we calculate a firm's industry-level scope 3 intensity (*INDUSTRY_SCOPE3_INTENSITY*) as follows:

$$INDUSTRY\_SCOPE3\_INTENSITY_{ikt} = \frac{\sum_k SCOPE3_{kt}}{\sum_k SALES_{kt}}, i\epsilon k.$$

We also calculate a firm's industry-level total internal emissions intensity (*INDUSTRY_TOTAL_INTENSITY*) as follows:

$$INDUSTRY\_TOTAL\_INTENSITY_{ikt} = \frac{\sum_k TOTAL_{kt}}{\sum_k SALES_{kt}}, i\epsilon k.$$

Both of these two instruments are calculated from our sample, and are highly correlated with each firm's Scope 3 emissions and total internal emissions, while not correlated with a firm's financial performance. Our last instrumental variable, renewable energy consumption rankings (*RANK*), orders the states by renewable energy use. States may demonstrate varying degrees of interest in imposing regulations that may help constrain GHG emissions (Reid and Toffel 2009). The consumption of renewable energy may be a signal of a state's interest in pursing green initiatives and policies. Hence, a firm headquartered in a state with a high level of renewable energy consumption may face more pressure to lower its GHG emissions. The ranking of a state according to its renewable consumption use is also expected not to be related to the financial performance of firms whose headquarters are located in the state. The above three instrumental variables are specified in the same period as total GHG emissions and Scope 3 emissions. We use the *xtivreg28* command in Stata 12.0 to estimate our model (Baum 2007). We also test the validity of our instruments and will discuss the results in the following section. The first stage results of our 2SLS model are included in the Online Appendix.

4. Results

To test Hypothesis 1, we estimate Equation (1) with our main independent variables as both binary (*ER*) and continuous (*CER*) separately. Table 4 reports the FGLS estimation results with panel-specific AR(1) and industry controls. Specifically, firms with any emissions reduction programs (or more programs in the case of the continuous measure) tend to have higher levels of supply chain emissions (0.143 for *ER*, $p < 0.05$, and 0.185 for *CER,* $p < 0.001$). This positive relationship supports our hypothesis that a supply chain leakage effect exists. Our results also show that *ASSETS* is positive and significant (0.512, $p < 0.001$), indicating that large firms have higher Scope 3 emissions than smaller firms. As expected, *CAPITAL_INTENSITY* is negative and significant (-0.352, $p < 0.001$), showing that capitally inefficient firms tend to have lower supply chain emissions. *PPE*, or plant and equipment, of a firm indicates the extent to which the firm is focused on manufacturing activities, and is positive and significant (0.157, $p < 0.001$). A firm's energy consumption, *ENERGY*, also has a significant, positive effect on Scope 3 emissions (0.270, $p < 0.001$). If a firm consumes more energy in its production processes, *ceteris paribus*, it is likely that its supply chain does too. The coefficients of the control variables with the continuous measure of emissions reduction (*CER*) are mostly consistent with those with ER.

[Insert **Table 4** about Here]

To test the second hypothesis, we employ a two-stage-least-squares approach with additional instruments to treat the endogeneity issues associated with Scope 3 emissions and total internal emissions. We estimate Equation (2) with fixed time and firm effects, clustered by industry to account for the heterogeneity in reporting. First, we find that *TOTAL* is negative and marginally significant (-0.139, $p < 0.10$), which indicates that a higher level of firm internal emissions is associated with a lower level of firm financial performance, in line with the literature (Matsumura, Prakash and Vera-Muñoz 2013). In other words, the market may penalize firms with worse emissions performance, which damages firm reputation and future sales. Firms with a higher level of emissions may also have a lower efficiency in emissions control, which may reduce firm financial performance. However, *SCOPE_3* is positive and significant (0.029, $p < 0.05$), which suggests that a higher level of supply chain emissions may benefit a firm financially. This result supports our second hypothesis and, combined with the negative financial effect of a firm's internal emissions, may explain the motivation of the supply chain leakage of GHG emissions.

We report our two-stage instrumental variable estimation model results in Table 5. For control variables, our results suggest that capital intensity is negatively related to a firm's *ROA* (-0.116; $p < 0.001$), while a firm's leverage is significant and negative (-0.020; $p<0.001$). These are consistent with previous research. This suggests that capital-intensive firms may possess expensive capital assets such as plants, factories and equipment that may require long periods of use to produce an adequate return on assets (Miller and Cardinal 1994). And firms with a higher financial leverage may be burdened with debt, and are more likely to gain lower returns (Hart and Ahuja 1996; King and Lenox 2001).

[Insert **Table 5** about Here]

Because of the critical role of Scope 3 emissions and measurement errors, we further report and discuss the instruments. We conduct several tests following Baum, Schaffer and Stillman (2007) to check for weak instruments that could produce biased IV estimators (Horowitz 2011). In the first stage of our two-stage model, the test of our instruments for *TOTAL* and *SCOPE_3* emissions suggests that the instruments have significant explanatory power (Staiger and Stock 1994). The F statistics (p-value) are 126.35 ($p<0.001$), and 25.68 ($p<0.001$), respectively, for those two variables. Next, we perform the under-identification test of instruments (Cragg and Donald 1993). The Anderson Canonical Correlation LR statistic is 44.69 ($p<0.001$). The null hypothesis for this test is that the minimum canonical correlation is zero. If the first-stage equations are to be identified, then all of the canonical correlations should differ significantly from zero. Our test results reject this null hypothesis, indicating that our first-stage equations are not under-identified. Last, our Hanson J over-identification test shows a chi-square statistic that is equal to 8.65 ($p=0.566$), indicating that our instruments are not significantly correlated with the error term in the second-stage equation. This supports the exogeneity of our instruments.

In summary, our two main hypotheses are both supported by the above findings. Implementation of emissions reduction programs may likely be treated favorably in the market and amongst the stakeholders, but it may also lead to higher supply chain emissions. The financial implication of leakage is also confirmed—the leakage of emissions to the supply chain may be rewarded while internal emissions are punished.

4.1. Robustness Tests

To further test the validity of our data and the analysis, we conduct a number of additional analyses to check robustness of our main results: alternative measures of independent and dependent variables, additional treatment of time and industry heterogeneity, and sub-sample analyses. Further, as a robustness test, we control for supplier disclosure of ESG information in estimating our main models, and we provide a discussion of the results.

First, our main results are obtained from FGLS estimations with panel specific AR(1) and treatments for heteroscedasticity. Although we control for industry heterogeneity, this method does not address firm heterogeneity, and may be subject to issues of smaller standard error (Hoechle 2007). We therefore estimate two sets of models: fixed effect model with Driscoll and Kraay standard errors to account for potential smaller standard error issue, and fixed effect models controlling for year and firm to address firm heterogeneity. As shown in the Online Appendix, the results are mostly consistent with those from the FGLS estimations. Second, one concern over the use of Scope 3 emissions is the changing standard in reporting Scope 3 emissions as well as the learning curve in reporting Scope 3. To address this issue, we conduct a subsample analysis using data from 2013-2015. Our rationale is that in 2011, the GHG protocol released the “Corporate Value Chain (Scope 3) Accounting and Reporting Standard”, allowing companies to assess their entire value chain emissions impact with a standardized methodology. Although the new standard came out in 2011, we did not include the year 2012 in the subsample analysis to account for the ambiguity and learning curve in adjusting to the new reporting standard. Hence, we use data from 2013-2015 to estimate Equation (1), and the results remain the same. Third, to further account for the size effect, we replace *SCOPE_3* and *TOTAL* in the estimation of the two equations with their respective emissions intensity (obtained by dividing the two variables by *ASSETS*). The main emission leakage results remain unchanged. The main results also remain the same when we replace *SCOPE_3* and *TOTAL* using their respective change, measured by the difference between last year’s Scope 3 emissions or total internal emissions level and those of the current year, and using their respective rate of change, measured by the change from the last year's emissions level divided by the last year's emissions level. Last but not least, while *ROA* is commonly used to evaluate firm financial performance, we replace *ROA* with an alternative measure, *Tobin's Q*, which is a commonly used measure to capture firm long-term value. We measure *Tobin's Q* in line with Kroes, Subramanian and Subramanyam (2012) and Dowell, Hart and Yeung (2000) as the sum of equity (end-of-year share price times the number of outstanding common shares), long-term debt, and net current liabilities divided by total assets. Scope 3 emissions remain positive and significant (0.152, $p<0.05$) while the total internal emissions are negative and significant (-0.557, $p<0.05$).

To further examine industry influence, we run a set of random coefficient models, allowing the relationship between emissions reduction programs and Scope 3 emissions to have both random intercepts and random coefficients at the industry level, and random intercepts at the firm level. This estimation approach creates a hierarchical industry-firm effect for each industry and better captures unique industry effects for Scope 3 emissions. The likelihood-ratio test that compares the random intercept and random coefficient models reports a chi-square statistics of 0.06 ($p=0.810$). This suggests that the random intercept model fits better than the random coefficient model. In other words, industry heterogeneity exists for Scope 3 emissions reporting, and the impact of emissions reduction programs on Scope 3 emissions does not significantly vary across industries. Nonetheless, we estimate a random coefficient model with random intercepts and a random slope to show that *ER* becomes insignificant (0.413, $p=0.154$) but *CER* remains positive and significant (0.446, $p<0.05$). To further check for robustness across industry, we use the two measures in Reid and Toffel (2008), i.e., a dummy for environmentally sensitive industries and a dummy indicating regulatory pressure. In the former case, the dummy variable is coded 1 if firms operate in these industries: mining, oil and gas extraction, utility, construction, manufacturing, and transportation (NAIC 21, 22, 23, 31, 32, 33, 48 and 49). In the latter case, we add another dummy variable to depict whether a firm is headquartered in a state likely to pose regulatory threats and operates in the following industries that are targeted for emissions reduction: mining, oil and gas extraction, utility, construction, manufacturing, and transportation (NAIC 21, 22, 23, 31, 32, 33, 48 and 49). We follow Reid and Toffel (2009) to select states with potential regulatory pressure – these states are either members of the Regional Greenhouse Gas Initiatives (RGGI) or Western Climate Initiative (WCI), starting the year the state joined either of these, and in 2006 for California. We add the two dummies separately and estimate Equation (1). We find that *ER* remains positive and significant after these industry effects are controlled.

Further, it has been shown that supplier disclosure of emissions information may influence how emissions information is collected, and therefore the reporting, calculation and performance of Scope 3 emissions (Hora and Subramanian 2013; Jira and Toffel 2013). We therefore estimate our main Scope 3 emissions equation controlling for a dummy variable, Supplier Disclosure. Supplier Disclosure is defined as "whether a supplier's guidelines, that encompass all Environmental, Social and Governance (ESG) areas, are publicly disclosed" (Source: Bloomberg ESG). If supplier reporting of environmental information, such as GHG emissions, affects Scope 3, Supplier Disclosure should be significant in the estimation of the updated model. Our estimations of the main models with Supplier Disclosure as an additional control show that Supplier Disclosure is not significant (0.043; $p=0.128$). While we do not rule out reporting issues completely, this result indicates that the reporting status of supply chain partners does not directly affect the relationship between *ER* (*CER*) and Scope 3, which remains positive and significant.

The robustness checks indicate that the data and modeling concerns unlikely affect the main findings of this research. The supply chain leakage effect and its connection to financial performance are mostly significant and consistent across different treatments. The detailed results discussed above are included in the Online Appendix.

5. Extensions

The focus of this research is to examine the supply chain leakage of firms' GHG emissions reduction efforts. While our main results have shown the presence of a leakage effect, some important questions remain that, if answered, may provide depth and breadth beyond the main results. This section explores a few such questions as extensions.

5.1. Total Supply Chain Emissions

We have shown that the existence of an emissions reduction program is often associated with a higher level of supply chain emissions, but it is unclear whether the overall supply chain may have a higher or lower level of GHG emissions—it is possible that even if the leakage effect exists, the combined emissions from the firm and its supply chain may be unchanged or even lower if internal emissions are indeed reduced. In this situation, the leakage effect is a redistribution of emissions along the supply chain, with a negligible or even favorable overall outcome. Alternatively, emissions reduction programs may increase the overall supply chain emissions leading to a negative impact on the environment. To examine these possibilities, we estimate Equation (1) with the total supply chain emissions, i.e., the sum of Scope 1, Scope 2, and Scope 3, as the dependent variable. The results are shown in Table 6. Interestingly, ER, the binary measure of emissions reduction, is insignificant while CER, the continuous measure, is positive and significant (0.173, $p < 0.05$). This finding indicates that having an emissions reduction program may not have a significant impact on total supply chain emissions. In other words, the leakage effect only moves emissions to the supply chain, without increasing the total emissions, whereas the cumulative effect of emissions reduction programs does increase total, supply chain-wide GHG emissions, creating a negative externality for the environment. The results remain the same when we replace the total supply chain emissions with the following alternative variables: the change of total supply chain emissions from previous year, and the rate of such change.

[Insert **Table 6** about Here]

5.2. Market Pressure

Literature indicates pressure for better emissions performance may come from stakeholders under increasing consumer awareness of GHG emissions. When consumers become sufficiently sensitive to firms' reputation for social responsibility, firms may incorporate emissions performance into strategic objectives to strengthen their competitive advantage. Firms may pursue an early adopter strategy, with some others following suit under pressure. Market competition, therefore, may affect supply chain emissions because firms may compete by engaging supply chains for green reputation purposes and/or to avoid the high costs associated with a green reputation. If competition is found to play a role in the leakage effect, it confirms the stakeholder pressure induced mechanism behind supply chain leakage. To examine market pressure, we include a measure for competition intensity, the Herfindahl-Hirschman Index (*HHI*), based on the two-digit NAIC code where higher *HHI* values equate to lower competition intensity. We estimate Equation (1) with *HHI* as an additional variable. The results, in Table 7, show that first, after controlling for *HHI*, *ER* and *CER* remain positive and significant (0.134, $p<0.01$; 0.185, $p<0.001$), and second, *HHI* is negative and significant (-0.229, $p<0.01$; -0.183, $p<0.05$). This result indicates that a firm in a more competitive market tends to have a higher level of Scope 3 emissions, which confirms the role of the market with increasing customer awareness of emissions.

[Insert **Table 7** about Here]

5.3. Regulatory Environment in Europe and Asia

A firm's regulatory environment, in addition to market competition, also creates emissions reduction pressure. GHG emissions regulations vary across countries, and global firms may react to their respective regulatory environment in terms of emissions reduction effort and leakage. More specifically, GHG emissions reporting is largely voluntary in the U.S., while some European countries such as the United Kingdom mandate such reporting in company annual reports (Lament 2015). European standards of GHG emissions are also more restrictive and comprehensive than the U.S. and most Asian countries. More transparency in Scope 3 emissions reporting in Europe is also well documented (Matisoff, Noonan and O'Brien 2013). The main findings of our paper are based on a sample of North American firms, which are mostly subject to similar regulatory pressure. In order to better understand the role of regulatory pressure as a potential driver in supply chain leakage of GHG emissions, we collect data on European firms and Asian firms from Bloomberg ESG. Given the fact that European firms usually operate under more rigorous emissions regulation than U.S. firms, while Asian firms operate under less, we hope to see a significant difference in the leakage effect. Both samples are from 2007 to 2014. The European sample has an unbalanced panel of 1,708 firm-year observations for 408 firms in 19 industries. The manufacturing industry accounts for about 30% of the sample observations. The Asian sample has an unbalanced panel of 528 observations for 137 firms in 17 industries. The manufacturing industry remains the major industry, accounting for 44% of the sample observations. For both samples, we run an FGLS model to examine the influence of emissions reduction programs, both the binary and continuous, on Scope 3 emissions. We report our results in Table 8.

[Insert **Table 8** about Here]

We find that emissions reduction programs are positively related to Scope 3 emissions for European firms (0.190; $p < 0.001$) but not significant for Asian firms (-0.690; $p=0.664$). This suggests that the emissions reduction efforts of European firms may indeed be linked to the leakage effect. However, this effect is not found among Asian firms. This finding confirms the potential source of the leakage effect related to regulatory pressure, as discussed earlier. The higher environmental standards, more transparent emissions information, and greater consumer awareness create higher pressure, under which firms are more incentivized to engage supply chains in emissions reduction efforts. The leakage effect is more likely as a result.

In sum, the extended studies in this section establish an overall negative externality in the supply chain, from a firm's emissions reduction programs. This shows a wider effect of the leakage in the supply chain, as the leakage may dominate the gains from the firm's own emissions reduction programs. Further, the fundamental logic of the leakage effect begins with pressure from market competition and government regulations to which the firm has to react. The extensions in this section empirically confirms such pressure.

6. Discussion and Conclusion

The objective of this research is to examine the supply chain emissions associated with a firm's emissions reduction efforts. We collected secondary data on GHG emissions from a firm and from a firm's supply chain, and estimated econometric models connecting supply chain emissions to the firm's emissions reduction programs, and further, to its financial performance. We show that a firm's efforts of emissions reduction may be related to negative environmental leakage in its supply chain. The reasons for such leakage may be varied. Under the pressures of consumer and stakeholder expectations and profitability objectives, a firm may commit to process improvements and relocating non-conforming activities, e.g., those with high GHG emissions, to its less visible supply chain. Technological innovations behind green products may require supply chains to take on more emissions, as in the case of Tesla. Our results indicate that firms with emissions reduction programs tend to have higher supply chain emissions, also known as Scope 3 emissions. While prior literature has considered the possibility and effects of emissions leakage within firm boundaries, our research contributes to the literature by demonstrating that such emissions leakage also occurs between a firm and its supply chain, whose members are not under direct control of the firm. In addition, we find that the emissions leakage may be associated with greater firm financial performance, highlighting the motivation behind the leakage. Our research therefore extends the firm-centric view of emissions reduction in the literature to the supply chain perspective.

Our extended studies find that the negative environmental leakage effect may further expand to the entire supply chain as the combined GHG emissions, for both the firm and its supply chain, may be higher with emissions reduction programs. This is the case where even if the firm's own emissions are lower with its emissions reduction programs, the negative emissions leakage in the supply chain may outweigh the lower internal emissions by the firm. This is an important finding as the stakeholders and consumers may interpret the lower internal emissions by the firm as indicating overall emissions reduction, and reward the firm with sales and market share. Confirming the pressure from stakeholders and government regulation, we find that market competition encourages the leakage effect. Consumer awareness of GHG emissions may create a greater pressure when the market is more competitive. A similar effect is found with regard to the strength of regulation, as European firms, usually under stricter government regulations, tend to have higher levels of supply chain leakage than their Asian counterparts.

The implications of this research to practitioners, policy makers and non-profit organizations are multifaceted. As a firm's commitment to reducing emissions may be accompanied by negative environmental leakage for supply chain members, managers should be encouraged to adopt a supply chain perspective in evaluating the effectiveness of emissions reduction programs. More importantly, while leaking GHG emissions to the supply chain may have direct financial benefit to the firm, as our results show, managers and other stakeholders should be mindful of the negative environmental effect to the supply chain. Similarly, government agencies and industry watchdog organizations should become aware of the financial motivation for the supply chain leakage, and implement effective mechanisms to improve supply chain transparency and supply chain accountability of emissions and reward systems. Our extended results on the roles of competition and regulatory intensity further highlight the impact of the leakage effect in situations where financial rewards for environmentally friendly signaling and where regulations appear stringent. A focus on better visibility and coverage of environmental responsibility in legislation and regulation will help improve supply chain wide emissions reduction. The strategy of outsourcing emitting activities or advancing technologies to satisfy lower GHG emissions expectations may be enabled by the opaqueness of supply chain activities. Yet, activities of NGOs like the knowthechain.org, along with requirements for transparency from regulators may erode the opaqueness of a firm's supply chain. And with the enhancement of information technologies and a continually growing public awareness of climate change, firms may face potential risks of public antagonism for having "dirty" supply chains. Hence, managers should be aware that while announcing an emissions reduction program can help promote a positive firm image, careful monitoring of supply chain activities may help to prevent the erosion of firm image. We also believe that the reporting of GHG emissions for the supply chain should be highly encouraged and be visible to the public. Evaluated with supply chain-wide information, a firm with low internal emissions may not be rewarded with revenue opportunities or market share if its supply chain emissions are high. If so, firms may then be more aware of unintended "shifting" of emissions to their supply chains. While some NGOs such as the CDP have already been asking firms to disclose emissions information, regulations should also be introduced – quite possibly, leakage may be internalized once emissions policies, such as an introduction of a carbon tax, become more stringent and comprehensive, and firms may be less likely to take advantage of their supply chain if they need to be responsible for their supply chain emissions. Further, policy makers may consider encouraging supply chain collaboration in emissions reduction to help reduce supply chain-level emissions, for instance, by establishing incentives for industry-wide collaboration.

The limitations of this study are mainly from the data sources and analyses. While we propose two measures of a firm's emissions reduction in our model estimation, emissions reduction programs are diverse and better measures are needed to develop further insight on the leakage effect. As more data become available, future research could examine the degree of firm effort toward emissions reduction and the effects on the firm and its supply chains. In addition, although we have considered and treated industry heterogeneity in our model, we believe industry sectors may play an important and interesting role in understanding emissions for both firms and their supply chains. Future research could investigate the degree of supply chain leakage across industries. Although it remains unclear to what extent our results of emissions reduction can be generalized to other environmental activities, we believe our research is a step forward toward better understanding the effects of firm emissions reduction efforts, especially the broader impacts in supply chains, and we hope our work will stimulate further work on the spillovers of firm sustainability initiatives.

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References

Apple "10-K Report," http://files.shareholder.com/downloads/AAPL/4317878969x0xS1193125-11-282113/320193/filing.pdf), 2011.

Apple "Environmental Responsibility Report," https://images.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2014.pdf), 2014.

Apple "Environmental Responsibility Report," https://images.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2015.pdf), 2015.

Apple "Environmental Responsibility Report," https://images.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2017.pdf), 2017.

Argyres, N.S. and T.R. Zenger "Capabilities, transaction costs, and firm boundaries," *Organization Science*, (23:6), 2012, pp 1643-1657.

Babiker, M.H. "Climate change policy, market structure, and carbon leakage," *Journal of international Economics*, (65:2), 2005, pp 421-445.

Barnett, M.L. and R.M. Salomon "Does it pay to be really good? Addressing the shape of the relationship between social and financial performance," *Strategic Management Journal*, (33:11), 2012, pp 1304-1320.

Baum, C.F. "Instrumental variables estimation in Stata," *Boston College*), 2007.

Baum, C.F., M.E. Schaffer and S. Stillman "Enhanced routines for instrumental variables/GMM estimation and testing," *Stata Journal*, (7:4), 2007, pp 465-506.

Blanco, C., F. Caro and C.J. Corbett "Operational Response to Climate Change: Do Profitable Carbon Abatement Opportunities Decrease Over Time?," *working paper*), 2016.

Blanco, C., F. Caro and C.J. Corbett "The state of supply chain carbon footprinting: Analysis of CDP disclosures by US firms," *Journal of Cleaner Production*), 2016.

Blanco, C., F. Caro and C.J. Corbett "The state of supply chain carbon footprinting: analysis of CDP disclosures by US firms," *Journal of Cleaner Production*, (135), 2016, pp 1189-1197.

Bound, J., C. Brown and N. Mathiowetz "Measurement error in survey data," *Handbook of econometrics*, (5), 2001, pp 3705-3843.

Busch, T. "Corporate carbon performance indicators revisited," *Journal of Industrial Ecology*, (14:3), 2010, pp 374-377.

Busch, T. "Which emissions do we need to account for in corporate carbon performance? Response to Murray and colleagues," *Journal of Industrial Ecology*, (15:1), 2011, pp 160-163.

Capon, N., J.U. Farley and S. Hoenig "Determinants of financial performance: a meta-analysis," *Management science*, (36:10), 1990, pp 1143-1159.

Carbon, P. "Carbon 2006: Towards a truly global market," *Copenhagen, Norway*), 2006.

Caro, F., C.J. Corbett, T. Tan and R. Zuidwijk "Double counting in supply chain carbon footprinting," *Manufacturing & Service Operations Management*, (15:4), 2013, pp 545-558.

Carroll, R.J., D. Ruppert, L.A. Stefanski and C.M. Crainiceanu. *Measurement error in nonlinear models: a modern perspective*, CRC press, 2006.

CDP "CDP Climate Change Report 2015: The mainstreaming of low-carbon on Wall Street," https://www.cdp.net/en/research/global-reports/global-climate-change-report-2015), 2015.

CDP "Global Supply Chain Report 2017," https://www.cdp.net/en/research/global-reports/global-supply-chain-report-2017), 2017.

Chen, X., H. Hong and D. Nekipelov "Nonlinear models of measurement errors," *Journal of Economic Literature*, (49:4), 2011, pp 901-937.

Cheng, T.-F. "Apple 'conservative' on orders, says key supplier ASE," http://asia.nikkei.com/Business/AC/Apple-conservative-on-orders-says-key-supplier-ASE), 2016.

Clarkson, P.M., Y. Li, G.D. Richardson and F.P. Vasvari "Does it really pay to be green? Determinants and consequences of proactive environmental strategies," *Journal of Accounting and Public Policy*, (30:2), 2011, pp 122-144.

ClimateWire "Suppliers follow Wal-Mart's lead to reduce carbon emissions," http://midwestenergynews.com/2013/05/23/suppliers-follow-wal-marts-lead-to-reduce-carbon-emissions/), 2013.

Cole, N.L. "CO2 Emissions Growth Takes a Bite Out of Apple's Sustainability Claims," http://www.truth-out.org/news/item/30346-co2-emissions-growth-takes-a-bite-out-of-apple-s-sustainability-claims), 2015.

Copeland, B.R. and M.S. Taylor "Trade, growth, and the environment," *Journal of Economic Literature*, (42:1), 2004, pp 7-71.

Cragg, J.G. and S.G. Donald "Testing identifiability and specification in instrumental variable models," *Econometric Theory*, (9:02), 1993, pp 222-240.

Delmas, M.A. and M.W. Toffel "Organizational responses to environmental demands: Opening the black box," *Strategic Management Journal*, (29:10), 2008, pp 1027-1055.

Delmas, M.A. and M.W. Toffel "Institutional pressures and organizational characteristics: Implications for environmental strategy,"), 2010.

Deutsch, C.H. "Companies giving green an office," *New York Times*, (3), 2007.

Dong, Y. and M. Dresner "Supply chain learning and spillovers in vendor managed inventory," *Decision Sciences*, (43:6), 2012, pp 979-1001.

Dowell, G., S. Hart and B. Yeung "Do corporate global environmental standards create or destroy market value?," *Management science*, (46:8), 2000, pp 1059-1074.

EIA https://www.eia.gov/), 2010.

Facanha, C. and A. Horvath "Environmental assessment of logistics outsourcing," *Journal of Management in Engineering*, (21:1), 2005, pp 27-37.

Fisher-Vanden, K. and K.S. Thorburn "Voluntary corporate environmental initiatives and shareholder wealth," *Journal of Environmental Economics and Management*, (62:3), 2011, pp 430-445.

Flammer, C. "Does corporate social responsibility lead to superior financial performance? A regression discontinuity approach," *Management Science*, (61:11), 2015, pp 2549-2568.

Fu, W., B. Kalkanci and R. Subramanian "Are Hazardous Substance Rankings Effective?," *working paper*), 2017.

Gaur, V., M.L. Fisher and A. Raman "An econometric analysis of inventory turnover performance in retail services," *Management science*, (51:2), 2005, pp 181-194.

Ghemawat, P. "Making differences: The central challenge of global strategy," *Transnational management: Text, cases, and readings in cross-border management*), 2011, pp 278-289.

Greenpeace "Guide to Green Electronics," http://www.greenpeace.org/international/global/international/publications/climate/2012/guidegreenerelectronics/apple.pdf), 2012.

Hansen, C.B. "Generalized least squares inference in panel and multilevel models with serial correlation and fixed effects," *Journal of Econometrics*, (140:2), 2007, pp 670-694.

Harris, E. *The voluntary carbon offsets market: An analysis of market characteristics and opportunities for sustainable development*, IIED, 2007.

Hart, S.L. and G. Ahuja "Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance," *Business Strategy and the Environment*, (5:1), 1996, pp 30-37.

Hausman, J. "Mismeasured variables in econometric analysis: problems from the right and problems from the left," *The Journal of Economic Perspectives*, (15:4), 2001, pp 57-67.

Hoechle, D. "Robust standard errors for panel regressions with cross-sectional dependence," *Stata Journal*, (7:3), 2007, pp 281.

Hoffman, A.J. "Climate change strategy: The business logic behind voluntary greenhouse gas reductions," *California Management Review*, (47:3), 2005, pp 21-46.

Hoffman, V. and T. Busch "Corporate carbon performance indicators: carbon intensity, dependency, exposure, and risk," *Journal of Industrial Ecology*, (12:4), 2008, pp 505-520.

Hora, M. and R. Subramanian "Relationship between Environmental Disclosures and Environmental Performance,"), 2013.

Horowitz, J.L. "Applied nonparametric instrumental variables estimation," *Econometrica*, (79:2), 2011, pp 347-394.

Jacobs, B., R. Subramanian, M. Hora and V. Singhal. "Market Value Implications of Voluntary Corporate Environmental Initiatives (CEIs)." *Sustainable Supply Chains*, Springer.

Jacobs, B.W. "Shareholder Value Effects of Voluntary Emissions Reduction," *Production and operations management*, (23:11), 2014, pp 1859-1874.

Jacobs, B.W., V.R. Singhal and R. Subramanian "An empirical investigation of environmental performance and the market value of the firm," *Journal of operations management*, (28:5), 2010, pp 430-441.

Jira, C. and M.W. Toffel "Engaging supply chains in climate change," *Manufacturing & Service Operations Management*, (15:4), 2013, pp 559-577.

King, A. and M. Lenox "Exploring the locus of profitable pollution reduction," *Management science*, (48:2), 2002, pp 289-299.

King, A.A. and M.J. Lenox "Does it really pay to be green? An empirical study of firm environmental and financial performance: An empirical study of firm environmental and financial performance," *Journal of Industrial Ecology*, (5:1), 2001, pp 105-116.

Klassen, R.D. and C.P. McLaughlin "The impact of environmental management on firm performance," *Management science*, (42:8), 1996, pp 1199-1214.

Klassen, R.D. and S. Vachon "Collaboration and evaluation in the supply chain: The impact on plant-level environmental investment," *Production and operations management*, (12:3), 2003, pp 336-352.

Koebler, J. "Apple Forces Recyclers to Shred All iPhones and MacBooks," https://motherboard.vice.com/en_us/article/apple-recycling-iphones-macbooks), 2017.

Kolk, A., D. Levy and J. Pinkse "Corporate responses in an emerging climate regime: the institutionalization and commensuration of carbon disclosure," *European Accounting Review*, (17:4), 2008, pp 719-745.

Kolk, A. and J. Pinkse "Business responses to climate change: identifying emergent strategies," *California Management Review*, (47:3), 2005, pp 6-20.

Korten, D.C. *When corporations rule the world*, Berrett-Koehler Publishers, 2015.

Kostova, T., K. Roth and M.T. Dacin "Institutional theory in the study of multinational corporations: A critique and new directions," *Academy of management review*, (33:4), 2008, pp 994-1006.

Kroes, J., R. Subramanian and R. Subramanyam "Operational compliance levers, environmental performance, and firm performance under cap and trade regulation," *Manufacturing & Service Operations Management*, (14:2), 2012, pp 186-201.

Lament, M. "Trends in corporate social responsibility (CSR) reporting," *International Journal of Economic Practices and Theories*, (5:5), 2015, pp 503-509.

Lee, S.-Y., R.D. Klassen, A. Furlan and A. Vinelli "The green bullwhip effect: Transferring environmental requirements along a supply chain," *International journal of production economics*, (156), 2014, pp 39-51.

Madsen, P.M. "Does corporate investment drive a “race to the bottom” in environmental protection? A reexamination of the effect of environmental regulation on investment," *Academy of Management Journal*, (52:6), 2009, pp 1297-1318.

Marquis, C., M.W. Toffel and Y. Zhou "Scrutiny, norms, and selective disclosure: A global study of greenwashing," *Organization Science*, (27:2), 2016, pp 483-504.

Matisoff, D.C., D.S. Noonan and J.J. O'Brien "Convergence in environmental reporting: assessing the Carbon Disclosure Project," *Business Strategy and the Environment*, (22:5), 2013, pp 285-305.

Matsumura, E.M., R. Prakash and S.C. Vera-Muñoz "Firm-value effects of carbon emissions and carbon disclosures," *The Accounting Review*, (89:2), 2013, pp 695-724.

McConnell, J.J. and H. Servaes "Equity ownership and the two faces of debt," *Journal of financial economics*, (39:1), 1995, pp 131-157.

Meijer, E. and T. Wansbeek "Measurement error in a single regressor," *Economics Letters*, (69:3), 2000, pp 277-284.

Miller, C.C. and L.B. Cardinal "Strategic planning and firm performance: A synthesis of more than two decades of research," *Academy of Management Journal*, (37:6), 1994, pp 1649-1665.

Moorhead, J. and T. Nixon "Global 500 greenhouse gases performance 2010-2013: 2014 report on trends," *A Thomson Reuters Financial and Risk White Paper*), 2014.

Muthulingam, S. and A. Agrawal "Does Quality Knowledge Spillover at Shared Suppliers? An Empirical Investigation," *Manufacturing & Service Operations Management*, (18:4), 2016, pp 525-544.

Muthulingam, S., C.J. Corbett, S. Benartzi and B. Oppenheim "Energy efficiency in small and medium-sized manufacturing firms: order effects and the adoption of process improvement recommendations," *Manufacturing & Service Operations Management*, (15:4), 2013, pp 596-615.

Ortiz-de-Mandojana, N. and P. Bansal "The long-term benefits of organizational resilience through sustainable business practices," *Strategic Management Journal*), 2015.

Palmer, K., W.E. Oates and P.R. Portney "Tightening environmental standards: The benefit-cost or the no-cost paradigm?," *The Journal of Economic Perspectives*, (9:4), 1995, pp 119-132.

Petersen, K.J., R.B. Handfield and G.L. Ragatz "Supplier integration into new product development: coordinating product, process and supply chain design," *Journal of operations management*, (23:3), 2005, pp 371-388.

Plambeck, E.L. "Reducing greenhouse gas emissions through operations and supply chain management," *Energy Economics*, (34), 2012, pp S64-S74.

Plambeck, E.L. and L. Denend "Wal-Mart's sustainability strategy," *Palo Alto: Stanford GSB*), 2007.

Porter, M.E. and C. Van der Linde "Toward a new conception of the environment-competitiveness relationship," *The Journal of Economic Perspectives*), 1995, pp 97-118.

Rau, A., R. Toker and J. Howard "Can technology really save us from climate change," *Harvard business review*, (88:1/2), 2010, pp 21-23.

Reid, E.M. and M.W. Toffel "Responding to public and private politics: Corporate disclosure of climate change strategies," *Strategic Management Journal*, (30:11), 2009, pp 1157-1178.

Reinaud, J. "Issues behind competitiveness and carbon leakage," *Focus on Heavy Industry. Paris: IEA. IEA Information Paper*, (2), 2008.

Rose, J.M. "Corporate directors and social responsibility: Ethics versus shareholder value," *Journal of Business Ethics*, (73:3), 2007, pp 319-331.

Rosen, J. "More companies are tracking carbon emissions — is it helping?," https://www.greenbiz.com/article/more-companies-are-tracking-carbon-emissions-it-helping), 2016.

Scherer, A.G. and G. Palazzo "Globalization and corporate social responsibility,"), 2008.

Serpa, J.C. and H. Krishnan "The impact of supply chains on firm-level productivity," *Management science*), 2017.

Sodhi, M.S. "Conceptualizing Social Responsibility in Operations Via Stakeholder Resource-Based View," *Production and Operations Management*, (24:9), 2015, pp 1375-1389.

Staiger, D.O. and J.H. Stock. "Instrumental variables regression with weak instruments." National Bureau of Economic Research Cambridge, Mass., USA.

Straughan, R.D. and J.A. Roberts "Environmental segmentation alternatives: a look at green consumer behavior in the new millennium," *Journal of consumer marketing*, (16:6), 1999, pp 558-575.

Surroca, J., J.A. Tribó and S.A. Zahra "Stakeholder pressure on MNEs and the transfer of socially irresponsible practices to subsidiaries," *Academy of Management Journal*, (56:2), 2013, pp 549-572.

Vachon, S. and R.D. Klassen "Environmental management and manufacturing performance: The role of collaboration in the supply chain," *International journal of production economics*, (111:2), 2008, pp 299-315.

Wade, L. "Tesla's Electric Cars Aren't As Green As You Might Think," https://www.wired.com/2016/03/teslas-electric-cars-might-not-green-think/), 2016.

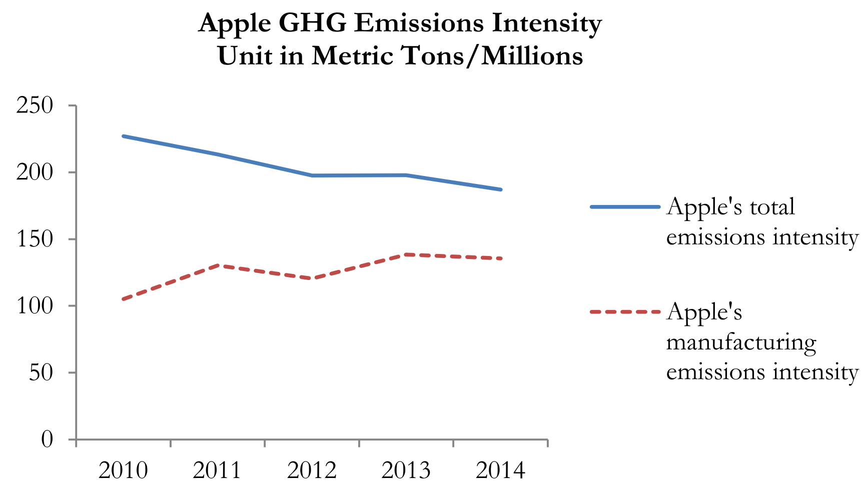
Walley, N. and B. Whitehead "It's not easy being green," *Harvard business review*, (72:3), 1994, pp 46-51.

Walley, N. and B. Whitehead "It's not easy being green," *Reader in Business and the Environment*, (36), 1994, pp 81.

White, A.L., M. Becker and D.E. Savage "Environmentally smart accounting: Using total cost assessment to advance pollution prevention," *Pollut. Prev. Rev.*, (3:3), 1993, pp 247-259.

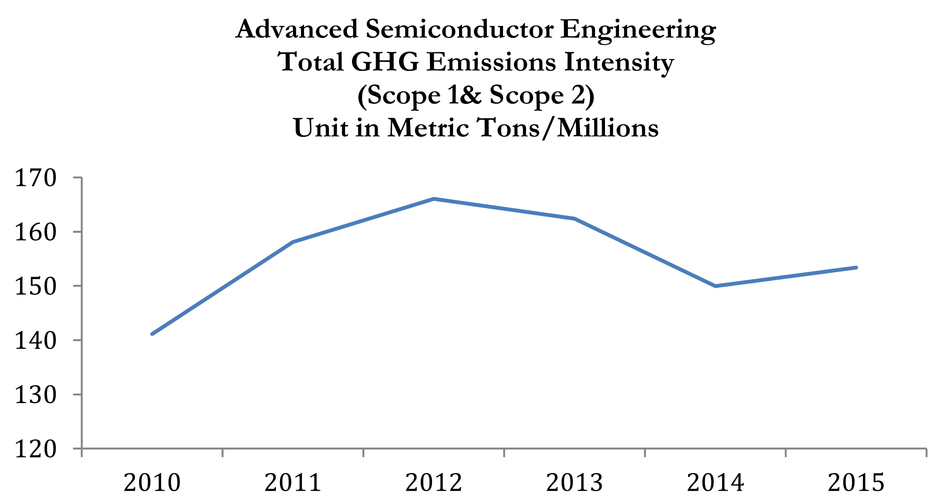
Witt, M.A. and A.Y. Lewin "Outward foreign direct investment as escape response to home country institutional constraints," *Journal of International business studies*, (38:4), 2007, pp 579-594.

Figure 1



Source:
Apple's CSR reports and Bloomberg ESG data[6]

Figure 2



Source:
Calculated from ASE's CSR reports and Compustat database[7]

[6] Calculations can be provided upon request.
[7] Ibid.

Table 1. Variable Description

Variable	Description
ROA	A continuous variable representing firm financial performance and is calculated as the ratio between firm net income and total assets. The variable is calculated based on the variables obtained from Compustat.
SCOPE_3	A continuous variable indicating all non-Scope 2, indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting company, electricity-related activities (e.g. transmission & distribution losses) not covered in Scope 2, outsourced activities, waste disposal, and etc. The variable is obtained from Bloomberg ESG.
TOTAL	A continuous variable indicating the combination of Scope 1 and Scope 2 emissions; Scope 1 Emissions are emissions from sources that are owned or controlled by the reporting company, and Scope 2 Emissions are emissions that are a consequence of the activities of the reporting company, but that occur at sources owned or controlled by another entity. The variable is obtained from Bloomberg ESG.
ER	A dummy variable indicating whether the company has set GHG emissions targets, or has disclosed any goal to reduce GHG emissions via any initiatives in its annual reporting period, with 1 (0) representing yes (no). The variable is obtained from Bloomberg ESG.
CER	A continuous variable indicating the cumulative effect of firms' emissions reduction programs during the sample period. The variable is calculated based on the variables obtained from Bloomberg ESG.
ASSETS	A continuous control variable for firm size. The variable is obtained from Compustat.
CAPITAL INTENSITY	A continuous control variable and is calculated by dividing capital expenditures by sales. The variable is obtained from Compustat.
ENERGY	A continuous control variable representing energy directly consumed by a firm through combustion in owned or controlled boilers, furnaces, vehicles, or through chemical production in owned or controlled process equipment. The variable is obtained from Bloomberg ESG.
PPE	A continuous control variable representing the scale and scope of a firm's facilities and the costs associated with them. The variable is obtained from Compustat.
LEVERAGE	A continuous control variable for firm debt burden and is calculated as the ratio of debt to total firm assets. The variable is calculated based on variables obtained from Compustat.

Table 2. Descriptives Statistics

	Variable	Mean	S.D.	Min	Max	1	2	3	4	5	6
1	Return on Assets (ROA)	0.10	-0.08	-0.63	0.49	1					
2	Total GHG Emissions	4,049.20	-9,720.12	0.49	75,549	-0.12***	1				
3	Scope 3 Emissions	6,635.10	-34,729.15	0.04	528,563	-0.02	0.34***	1			
4	Emissions Reduction (ER)	0.90	-0.32	0	1	0.00	0.10**	0.02	1		
5	Cumulative Emissions Reduction (CER)	8.10	-7.03	0	40	0.08*	-0.06	-0.02	0.32***	1	
6	Total Assets	145,759.90	380,000	23.32	2,573,126	-0.13***	-0.08*	-0.01	0.08**	0.12***	1
7	Capital Intensity	4.60	-6.95	0.12	36.63	-0.22***	-0.14***	-0.08**	0.07*	0.09**	0.64**
8	Financial Leverage	0.20	-0.16	0	1.51	-0.21***	0.06	-0.05	0.07*	0.04	-0.13**
9	Property Plant and Equipment	19,614.50	-42,256.98	0	340,277	-0.05	0.27***	0.33***	0.12***	0.14***	0.26**
10	Energy Consumption	11,278.70	-31,458.20	0.68	257,500	-0.11***	0.95***	0.36***	0.09*	-0.05	-0.08*

* p<0.05, ** p<0.01, *** p<0.001

Table 3. Industries and Firms

NAICS	Industry Name	Firms
11	Agriculture, Forestry, Fishing and Hunting	1
21	Mining, Quarrying, and Oil and Gas Extraction	14
22	Utilities	17
23	Construction	3
31	Manufacturing	16
32	Manufacturing	29
33	Manufacturing	41
42	Wholesale Trade	4
44	Retail Trade	7
45	Retail Trade	2
48	Transportation and Warehousing	10
49	Transportation and Warehousing	2
51	Information	23
52	Finance and Insurance	36
53	Real Estate and Rental and Leasing	13
54	Professional, Scientific, and Technical Services	9
56	Administrative and Support and Waste Management and Remediation Services	4
62	Health Care and Social Assistance	2
72	Accommodation and Food Services	8
99	Others	1

Table 4. FGLS Estimates with Panel Specific AR(1) – Scope 3

Variables	Coefficients	
Emissions Reduction (ER)	0.143*** (0.050)	
Emissions Reduction Cumulative (CER)		0.185*** (0.026)
Assets	0.512*** (0.064)	0.553*** (0.066)
Capital Intensity	-0.352*** (0.059)	-0.351*** (0.066)
PPE	0.157*** (0.049)	0.071 (0.052)
Energy Use	0.270*** (0.032)	0.312*** (0.036)
Industry	Yes	Yes
Observations	662	662
Model fit – χ^2	1186.61	1009.24
p-value	0.000	0.000

Standard errors are shown in parentheses. * $p < .10$; ** $p < .05$; *** $p < .01$

Table 5. Two Stage Least Square Estimates – ROA (2nd Stage with ER and CER)#

Variables	Coefficients	
	ER	*CER*
SCOPE 3	0.029**	0.030**
	(0.014)	(0.014)
TOTAL	-0.137*	-0.158***
	(0.081)	(0.035)
Assets	0.053	0.057
	(0.059)	(0.055)
Capital Intensity	-0.117***	-0.116***
	(0.026)	(0.026)
Leverage	-0.020***	-0.021***
	(0.005)	(0.004)
Time	Yes	Yes
Firm	Yes	Yes
Observations	362	362
Model fit – F	40.43	49.56
Probablity > F	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01
Note: # 1st Stage results can be found in the Online Appendix.

Table 6. FGLS Estimates with Panel Specific AR(1) – Total Supply Chain

Variables	Coefficients	
Emissions Reduction (ER)	0.004	
	(0.017)	
Emissions Reduction Cumulative (CER)		0.173**
		(0.009)
Assets	0.299***	0.294***
	(0.020)	(0.029)
Capital Intensity	-0.208***	-0.192***
	(0.016)	(0.027)
PPE	0.035***	0.029**
	(0.011)	(0.014)
Energy Use	0.598***	0.567***
	(0.023)	(0.023)
Industry	Yes	Yes
Observations	639	639
Model fit – χ^2	16401.63	6516.20
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table 7. FGLS Estimates with Competition Intensity

Variables	**Coefficients**	
Emissions Reduction (ER)	0.134***	
	(0.051)	
Emissions Reduction Cumulative (CER)		0.185**
		(0.025)
HHI	-0.229***	-0.183**
	(0.074)	(0.091)
Assets	0.530***	0.529***
	(0.067)	(0.065)
Capital Intensity	-0.386***	-0.342***
	(0.063)	(0.062)
PPE	0.163***	0.060
	(0.053)	(0.054)
Energy Use	0.273***	0.290***
	(0.034)	(0.036)
Industry	Yes	Yes
Observations	662	662
Model fit – χ^2	1231.80	801.51
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table 8. FGLS Estimates with Asian and European Firms—Scope 3

Variables	**Coefficients**	
	Asian	*European*
Emissions Reduction (ER)	-0.069	0.190***
	(0.159)	(0.035)
Assets	0.102***	0.208***
	(0.015)	(0.014)
Capital Intensity	-0.024	-0.215***
	(0.026)	(0.031)
Energy Use	0.684***	0.627***
	(0.046)	(0.016)
Industry	Yes	Yes
Observations	416	1277
Model fit – χ^2	562.84	19288.95
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Online Appendix:

Table A.1. Fixed Effect Estimates with Driscoll and Kraay Standard Errors – Scope 3

Variables	Coefficients	
Emissions Reduction (ER)	0.515**	
	(0.177)	
Emissions Reduction Cumulative (CER)		0.361***
		(0.064)
Assets	0.813***	0.476*
	(0.314)	(0.273)
Capital Intensity	-0.532***	-0.562***
	(0.154)	(0.124)
PPE	0.260	-0.253
	(0.337)	(0.288)
Energy Use	0.107*	0.094*
	(0.056)	(0.059)
Time	Yes	Yes
Firm	Yes	Yes
Observations	693	693
Model fit – χ^2	376.83	115.55
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table A.2. Fixed Effect Estimates with Fixed Time and Industry– Scope 3

Variables	Coefficients	
Emissions Reduction (ER)	0.444**	
	(0.200)	
Emissions Reduction Cumulative (CER)		0.316***
		(0.089)
Assets	0.745***	0.685***
	(0.132)	(0.132)
Capital Intensity	-0.537***	-0.582***
	(0.197)	(0.197)
PPE	0.050	-0.055
	(0.063)	(0.063)
Energy Use	0.294***	0.300***
	(0.074)	(0.073)
Time	Yes	Yes
Industry	Yes	Yes
Observations	693	693
Model fit – χ^2	181.22	190.71
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table A.3. Fixed Effect Estimates with Fixed Time and Firm– Scope 3

Variables	**Coefficients**	
Emissions Reduction (ER)	0.471**	
	(0.208)	
Emissions Reduction Cumulative (CER)		0.331***
		(0.097)
Assets	0.666**	0.463
	(0.335)	(0.336)
Capital Intensity	-0.528**	-0.568**
	(0.267)	(0.266)
PPE	0.161	0.204
	(0.303)	(0.300)
Energy Use	0.084	0.079
	(0.102)	(0.101)
Time	Yes	Yes
Firm	Yes	Yes
Observations	693	693
Model fit – χ^2	5.35	5.92
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table A.4. Two Stage Least Square Estimates – Tobin's q

Variables	**Coefficients**	
	ER	*CER*
SCOPE 3	0.146**	0.142**
	(0.070)	(0.064)
TOTAL	-0.547***	-0.520**
	(0.245)	(0.255)
Assets	0.136	0.134
	(0.106)	(0.116)
Capital Intensity	-0.197**	-0.199**
	(0.096)	(0.088)
Leverage	-0.061***	-0.061***
	(0.012)	(0.012)
Time	Yes	Yes
Firm	Yes	Yes
Observations	345	345
Model fit – F	15.81	9.22
Probablity > F	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table A.5. Random Coefficient Models with Random Slope – Scope 3

Variables	Coefficients	
Emissions Reduction (ER)	0.413	
	(0.290)	
Emissions Reduction Cumulative (CER)		0.446***
		(0.169)
Assets	0.678***	0.630
	(0.086)	(0.086)
Capital Intensity	-0.948***	-0.931***
	(0.176)	(0.173)
PPE	-0.111***	0.121
	(0.041)	(0.041)
Energy Use	0.506***	0.523***
	(0.054)	(0.053)
Time	Yes	Yes
Firm	Yes	Yes
Observations	693	693
Model fit – χ^2	266.97	257.82
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table. A.6. FGLS Estimates with Alternative Industry Control—Scope 3

Variables	Coefficients	
	Environmentally Sensitive Industry	*State Public Policy Targeted Industry*
Emissions Reduction (ER)	0.221***	0.241***
	(0.051)	(0.063)
Assets	0.397***	0.241***
	(0.044)	(0.044)
Capital Intensity	-0.303***	-0.212***
	(0.048)	(0.049)
PPT	0.079**	0.132***
	(0.037)	(0.038
Energy Use	0.238***	0.372***
	(0.028)	(0.030)
Industry	1.564***	0.860***
	(0.110)	(0.122)
Observations	662	662
Model fit – χ^2	857.25	571.84
p-value	0.000	0.000

Standard errors are shown in parentheses. * p < .10; ** p¸< .05 ; *** p < .01

Table A.7. 2SLS First Stage Estimates – Scope 3

Variables	Coefficients	
Emissions Reduction (ER)	0.279**	
	(0.102)	
Emissions Reduction Cumulative (CER)		0.197*
		(0.108)
Assets	0.708	0.592
	(0.778)	(0.791)
Capital Intensity	-1.345***	-1.301***
	(0.203)	(0.203)
PPE	0.601	0.594
	(0.465)	(0.519)
Energy Use	0.043	0.047
	(0.128)	(0.134)
Rank	0.583*	0.494*
	(0.312)	(0.291)
Industry Scope 3 Intensity	0.267**	0.245**
	(0.073)	(0.080)
Industry Total Intensity	0.184**	0.196**
	(0.084)	(0.082)
Time	Yes	Yes
Firm	Yes	Yes
Observations	362	362
Model fit – χ^2	132.80	116.36
p-value	0.000	0.000

Standard errors are shown in parentheses. * $p < .10$; ** $p < .05$; *** $p < .01$

Table A.8. FGLS Estimates with Panel Specific AR(1) – Scope 3 with Supplier Disclosure

Variables	**Coefficients**	
Emissions Reduction (ER)	0.161***	
	(0.044)	
Emissions Reduction Cumulative (CER)		0.199***
		(0.028)
Supplier Disclosure	0.043	-0.030
	(0.028)	(0.035)
Assets	0.473***	0.545***
	(0.065)	(0.067)
Capital Intensity	-0.368***	-0.382***
	(0.059)	(0.067)
PPE	0.164***	0.069
	(0.047)	(0.051)
Energy Use	0.321***	0.321***
	(0.030)	(0.036)
Industry	Yes	Yes
Observations	658	658
Model fit – χ^2	2895.90	1020.76
p-value	0.000	0.000

Standard errors are shown in parentheses. * $p < .10$; ** $p < .05$; *** $p < .01$