Supply Chain Network, ESG Ratings and Financial Performance

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Abstract

This paper presents a novel investigation by studying the role of supply chain network on firms' Environmental, Social, and Governance (ESG) performance as well as on financial performance. Our analysis employs comprehensive financial, board, ESG and supply chain data making an unbalanced panel of over 16,000 firm-year observations from 3,028 US publicly traded firms, spanning fiscal years from 2005 to 2021. Results from panel data regressions show that a large supply chain network exerts a positive and significant effect on ESG ratings, whereas the effect on financial performance is positive but not always significant. To corroborate our results, we use two different supply chain network proxies; namely the number of nodes and the eigenvector centrality, while we use various financial performance measures such as stock returns, ROA, ROE, ROS, and Tobin's Q. The results appear very consistent. Our study also provides several implications as it seems that supply chain directly impacts ESG and indirectly financial performance.

Keywords: supply chain; ESG ratings; financial performance; network analysis
JEL Classification: G11; G3; Q5

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1 Introduction

A thorough investigation of developments in supply chain network is important to better understand the firms' total sustainability performance, while such developments imply considerable implications for firms' managers and firms' investors (shareholders). The extant literature supports the important role of a supply chain network to generate value for firms. For instance, Hearnshaw and Wilson (2013) document that the properties of efficient supply chains can be reflected by a scale-free network, a type of network which is characterised by the presence of large hub firms. Bellamy et al. (2014) show that higher levels of supply network accessibility and supply network interconnectedness contribute to a greater innovation output for firms. Kim et al. (2015) indicate that a failure in a node or connecting arc may interrupt the flow of material across network and consequently the network structure significantly influences the likelihood of disruption. Dahlmann and Roehrich (2019) demonstrate that firms engage with supply chain partners with aim to reduce uncertainty in terms of information asymmetry. Finally, Gualandris et al. (2021) show that supply chain density positively associates with supply chain transparency.

Our study is associated with the supply chain network and environmental, social, and governance (ESG) ratings (also known as ESG pillars) literature. In this respect, a sustainable supply chain network may help firms to minimise the adverse impact of their environmental (reduce carbon footprint), social (diminish unequal employment opportunities) and governance (eliminate corruption and unethical practices) components. This implies that a sustainable supply chain network contributes to improvements in ESG ratings (see Tamayo-Torres et al., 2019). Similarly, Koberg and Longoni (2019) suggest that supply chain management is important to improve a firms' ESG performance.

Furthermore, given that ESG pillars are non-financial factors, our study is also related to the supply chain network and financial performance literature. In this regard, Wagner et al. (2012) argue the higher the supply chain fit, the higher the financial performance of the firm. Furthermore, Wang and Sarkis (2013) document that a sustainable supply chain network could be associated with developments in financial performance. In addition to this, Shi and Yu (2013) review the existing literature regarding the impact of supply chain management on firm-level financial performance. They indicate that an effective supply chain management enhances financial performance through improvements in revenue growth, working capital efficiency and operating costs reduction. In the same line of reasoning, Busse et al. (2017) demonstrate that supply chain visibility can cause higher profitability for firms. In turn, this generates an impact on the evaluation of firms via lower costs and higher profits. In this regard, the aim of our paper is to investigate the impact of supply chain network on the ESG performance and the financial performance of US related firms over the period from January 2005 to December 2021.

It follows that, on the one hand, a weakness supply chain network or a potential disruption in supply chain may cause firms to operate in a poor performance. For instance, we mention the negative impact that potential supply chain issues could generate on the firms' profile and reputation which in turn create concerns regarding firms' credibility and consequently may lead to poor business conditions. On the other hand, a weakness supply chain network may help firms to identify alternative suppliers and thus to maintain and enhance the sustainability of the supply chain. In this respect, a sustainable supply chain provides a guarantee that firms could limit their risks, promote their growth, protect their brands and build on investors' confidence and loyalty. To this end, the higher the standards of suppliers, the lower the possibility of poor business conditions.

With these considerations in mind, supply chain processes may signal crucial implications in firms' generic performance and thus it reflects the focal point in our study. We note that the existing literature concentrates on different measurements of supply chain network structures. For instance, Bellamy et al. (2014) use information centrality as a measure of supply network accessibility. Furthermore, Basole et al. (2017) use eigenvector centrality and firm's ego (network) density. In addition, Luo et al. (2023) employ degree centrality, PageRank centrality, clustering coefficients and structural holes.

In our study, we particularly attempt to extend the limited literature by employing the eigenvector centrality with aim to capture the supply network centrality. The eigenvector is not just a measure of ranking order centrality among nodes but more importantly a measure that computes ranking as a function of direct connection to ties and proximity to nodes with high degree of centrality throughout the network (see, for example, Bonacich and Lloyd, 2001; Bonacich, 2007; Bienenstock and Bonacich, 2022). Put it differently, a position is central with respect to eigenvector centrality, if it is connected to other positions which have many connections.

Although our study uses the eigenvector centrality which is also employed by Basole et al. (2017) who emphasise on 114 firms from the electronics industry and use regression analysis during the period from 2005 to 2009, we contribute to the existing literature in the use of a variety of industries. For instance, we explore Energy, Materials, Industrials, Consumer Discretionary, Consumer Staples, Health Care, Financials, Information Technology, Communication Services, Utilities, and Real Estate. Our choice creates a sample of around 3,000 firms within eleven industries. Thus, we attempt to provide a comprehensive analysis with aim to show that the existence of a large supply chain network may contribute to the improvement of the ESG scores as well as improvements in firms' financial operation.

Our findings suggest that, extended supply chain network, either calculated as a total number of connections or as an eigenvector centrality, has a strongly positive impact on firms' ESG score, while the impact on financial performance does not appear to be always significant. This finding is very important as it has been established that ESG improves financial performance, and therefore ESG is a channel through which supply chain boosts profitability.

Our paper contributes in several ways to existing literature. First, it provides a novel investigation on the supply chain effect on firms. This strand of literature has been neglected so far. Second, it compliments the empirical literature on ESG and financial performance by showing that supply chain can be regarded as a component of ESG and financial performance. Finally, it provides important implications for firms, as they should take a closer look at their supply chain network and possibly try to increase the number of suppliers. This will not only secure the continuous operations of the firms but also will signal an improved ESG profile.

The rest of the paper is structured as follows: Section 2 describes the literature review and states the hypotheses. Section 3 describes the data, sample, variables, and the methodology of the study. Results are presented along with some discussion in Section 4. Section 5 provides some robustness checks.

Section 6 concludes.

2 Literature Review

2.1 Brief review of the literature

We begin this section by indicating that it is beyond the scope of this paper to provide a detailed description of the existing literature. Thus, we focus on two strands that form the basis of our analysis and we highlight the findings of previous key studies. The presented literature in the following paragraphs conveys important information on the developments to the two areas of interest.

With reference to the relationship between supply chain network and ESG ratings, Koberg and Longoni (2019) provide a systematic review of sustainable supply chain management in global supply chains. They document that sustainable supply chain management is anticipated to improve the ESG performance of the firm. Moreover, Tamayo-Torres et al. (2019) provide evidence of a positive relationship between supply chain management and ESG practices for a sample of US and European firms. In addition, Das (2024) employs a large set of Fortune Global 500 multinational firms to examine the predictive value of supply chain sustainability initiatives for ESG performance. Findings suggest that sustainability initiatives can lead to improvements in the ESG performance of the multinationals. Finally, Truant et al. (2023) revisit the literature on the relationship between supply chain management and ESG framework and highlight the importance to systematically monitor this relationship. More specifically, the authors highlight the ability of shareholders to create increasing pressure for sustainable supply chain management.

Turning to the relationship between supply chain network and financial performance, Dehning et al. (2007) examine the financial performance of supply chain management systems for 123 manufacturing firms. They find that improvements in such systems increase gross margin, inventory turnover, and return on sales. In addition, Wagner et al. (2012) examine the relationship between supply chain fit and the financial performance of the firm for a sample of 259 US and European manufacturing firms. They indicate that the higher the supply chain fit, the higher the financial performance of the firm which is captured by return on assets. Furthermore, Wang and Sarkis (2013) investigate the relationship of sustainable supply chain management with corporate financial performance for 500 US green firms ranked by Newsweek's green ranking. They find that sustainable supply chain management is positively associated with corporate financial performance which is approximated by return on assets and return on equity.

In the same line of reasoning, Kim and Henderson (2015) investigate the effects of supplier's dependency on a focal firm's financial performance using a sample of 1,144 US public firms. They show that a supplier's dependency increases the focal firm's performance in terms of return on assets and return on sales. Moreover, Basole et al. (2017) examine the influence of 114 firms' supply network in the electronics industry on its financial performance. They document that the density of the supply networks has a positive effect on firms' performance which estimated by the firm's return on assets, inventory over sales, and cost of goods sold over sales. Finally, Luo et al. (2023) examine the impact of a supply chain network on firms' stock market performance in China for both Shanghai and Shenzhen stock exchanges and conclude that network structures are significantly related to firms' financial (stock returns) performance.

2.2 The testable hypotheses

Given the previously mentioned literature, we attempt to investigate the anticipated relationship between supply chain network on the one hand and ESG performance and financial performance on the other hand. Therefore, we posit the following hypotheses:
H1: A larger supply chain network has a positive impact on firms' ESG performance.
A larger supply chain network is expected to improve practices such as communication and collaboration between a focal firm and its suppliers and further to expand its reputation and innovation. Furthermore, it helps to avoid over-dependance on a smaller number of suppliers. Such developments could reduce firms' waste to the environment, asymmetric communication with firms' employees, and corruption practices in the managerial team. Therefore, ESG ratings are expected to increase and the ESG performance to be substantially improved.
H2: A larger supply chain network has a positive impact on firms' financial performance.
A larger supply chain network is anticipated to provide delivery reliability and flexibility so that the firms' products will be available to customers, in a timely and cost-effective approach. In turn, this increases the sales, the revenues, and the market share. Furthermore, it generates efficiency which in turn reduces costs across the supply chain such as inventory costs and production costs. It appears that such improvements have a direct impact on the firms' fundamentals in terms of efficiency, liquidity, and profitability. Therefore, financial performance will be improved.

3 Research Design

Data

Consistent with the extant literature that examines the ESG performance (Benton, 2021; Graf-Vlachy et al., 2020; Shi and DesJardine, 2021), we sourced board-level data from BoardEx spanning the period from 2005 to 2021. The dataset encompassed details such as directors' gender, nationality, experience, and education. Additionally, we augmented this information with corporate governance data from REFINITIV and S&P Capital IQ for the same timeframe. We consider metrics such as institutional ownership, and ESG scores. Financial data such as total assets, leverage, Tobin's Q, stock return, ROA, ROE, and ROS are collected from Compustat. Finally, we employ data by Frésard et al. (2020), who constructed a dataset with the pairwise vertical relatedness for US firms (basic 10% granularity version; this is the 10% of all firm pairs with highest potential for vertical relatedness) for the period 1991-2021, and there were found more than 80 million pairwise connections. Our initial board of directors sample comprised approximately 1 million director-years, representing around 40,000 distinct directors across 13,000 worldwide firms over the sample period. Upon filtering for firms with available corporate, financial and supply chain data, our final sample is finalised in 3,028 US firms. Table 1 shows the composition of our sample based on year and industry. Our sample is quite heterogeneous spanning among different sectors.

[PLEASE INSERT Table 1 HERE]

Dependent Variables: ESG and financial performance

Consistent with prior research ESG performance scores were sourced from REFINITIV (Avramov et al., 2021; Hsu et al., 2021). The scoring system encompasses over 10,000, with values ranging from 0 to 100, where higher scores signify superior ESG performance. Our sample includes 3,028 firms with available scores categorised into the three overarching themes and ten distinct categories: (i) environmental (resource use, innovation, and emissions), (ii) social (workforce, human rights, community, and product responsibility), and (iii) governance (management quality, shareholders rights, and corporate social responsibility strategy). The use of ESG scores is in line with the existing literature in this field (see, for example, Das, 2024).

In terms of financial performance variables, we use a battery of different proxies. First, we consider Tobin's Q, is calculated as (Equity market value + Liabilities book value) / (Equity book value + Liabilities book value) and it measures market value of the company's equity capital (see Tamayo-Torres et al., 2019). Second, financial variable is the stock return which is measured as the logarithmic difference between the price of a stock at year t to $t-1$ (see Luo et al., 2023). Third, Return on Assets (ROA) which is the ratio of net income to total assets and shows firm profitability in relation to total assets (see Wagner et al., 2012). Fourth, Return on Equity (ROE) which is the ratio of net income to shareholders' equity and shows firm profitability in relation to equity value (see Wang and Sarkis, 2013). Finally, Return on Sales (ROS) which is the ratio of EBIT to sales and shows operating efficiency (see Kim and Henderson, 2015).

3.1 Independent: Supply Chain Centrality

Our aim is to analyse the impact of supply chain network on various performance variables. To this end, we assess the relative significance of each customer or supplier by examining their contributions to the networked economy. Typically, from a supplier matrix A, one can compute a simple degree centrality vector, **Nodes**, as the simple sum of each row:

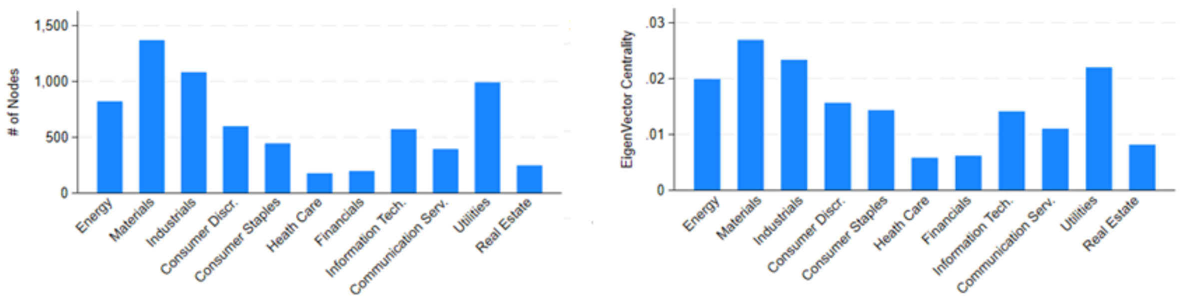
$$\mathbf{Nodes} = A\mathbf{e}, \tag{1}$$

where e denotes a vector of ones. However, degree centrality is a basic measure and does not account for the impact of each network. To address this limitation, we utilize eigenvector centrality (Bonacich, 1972). Eigenvector centrality is frequently used in financial research and has various applications, including analyzing CEO networks and supply chain networks (El-Khatib et al., 2015; Wu, 2015; Conti and Graham, 2020). The essence of this measure is that a customer can also serve as a supplier to other firms, and if this customer is a significant supplier to many other firms, its importance in the economy is notably enhanced. Unlike simply summing all suppliers in a network, eigenvector centrality assigns each supplier a weighted score based on the scores of its customers. Let c_i be the centrality measure for each firm i that is a supplier and let j be the costumer at year t and let w_i be the vertical relatedness between the two firms, (i.e., the supplier i and the costumer j). The eigenvector centrality of firm i is:

$$c_{i,t} = (\frac{1}{\lambda})\sum_i \sum_j w_{i,t} A_{i,j,t} c_{j,t}, \tag{2}$$

where $\lambda \mathbf{c} = \mathbf{Ac}$ as a matrix notation. Furthermore, λ denotes the largest eigenvalue of the supplier matrix A. The eigenvector centrality has an interesting property that it can be large either because a supplier (i) has many customers (j) or because it has important customers, or both. We normalise the measure to have comparable values across different years. To normalise it we sum all firms in the network to N, $\mathbf{e}^\top \mathbf{c}$ = N, where N is the number of firms in the network. With this normalisation, the average centrality does not vary with the size of the economy for each year given. Figure 1 displays the number of supply chains (on the left hand side) and the eigenvector centrality (on the right hand side) across different industries. As expected, manufacturing companies have more extended supply chain network.

Figure 1: Supply Chain Network per Sector



3.2 Econometric Method

In terms of identification of the impact of supply chain on the firm performance, we opt for a panel data model that considers heterogeneity across firms, years, and sectors. Equation 3 outlines the model below:

$$Y_{i,t} = \alpha_0 + \alpha_1 Supply_{i,t-1} + \alpha_2' \mathbf{Board_{i,t-1}} + \alpha_3' \mathbf{Financial_{i,t-1}} + \alpha_4' \mathbf{Year_t} + \alpha_5' \mathbf{Year_t} \times \mathbf{Sector_j} + u_{i,t}, \tag{3}$$

In Equation 3, the dependent variable, $Y_{i,t}$, the ESG scores (also decomposed into the Environment, Social, and Governance pillars) or financial performance (Tobin's Q, stock return, ROA, ROE, and ROS) for firm t at time (year) t, where $i = 1,2,...,N$, $t = 2005,2006,...,2021$, and $u_{i,t}$ is the random disturbance term. All explanatory variables are lagged one year to capture spurious relationships. The key explanatory variable, $Supply$, which measures the supply chain network (either LN(Nodes) or Eigen). Next, we include a set of $\mathbf{Financial_{i,t-1}}$ (LN(TA)), Leverage, Inst ownership, and Tobin's Q, Inefficiency, and liquidity risk), and $\mathbf{Board_{i,t-1}}$ (Gender %, Foreign directors %, Board Size, Network of directors, Experience, Education) variables. We also control for firm fixed effects. The use of year fixed effects allow us to account for an unobserved time variation in the data that is not already captured by the time-varying covariates. The year $\times$ sector fixed effects are theoretically motivated. In this regard, pursuant to the institutional theory, organisations operating in the same industry and facing similar institutional pressures converge on institutional norms in terms of sustainable development through coercive, mimetic, and normative processes (DiMaggio and Powell, 1983; Escobar and Vredenburg, 2011). Specifically, normative isomorphism predicates that product certifications, as well as professional accreditations, conventions, and standards evolve into organisational norms at the industry level (DiMaggio and Powell, 1983). The estimated coefficient standard errors are robust to autocorrelation and heteroscedasticity.

Table 5 lists the variables with their definitions and their sources. In addition, Table 2 shows the descriptive statistics of firms. The mean of the LN(Nodes) is 5.2 which indicates that firms have on average around 200 important supply chain connections with the maximum number being 3,760. In terms of our firm size (see LN(TA)), our firms have on average \$3.4 billion size with the maximum being \$3.3 trillion.

[PLEASE INSERT Table 2 HERE]

4 Empirical Results and Discussion

4.1 The relationship between supply chain network and ESG ratings

Table 3 summarises the results regarding the impact of supply chain network (either eigenvector centrality or nodes) on the ESG ratings either collectively or individually (environmental, social, and governance components). The findings in columns 1 and 5 provide evidence that the supply chain network has indeed an impact on ESG ratings collectively and this impact is positive and highly significant. Similarly, our findings in columns 2 and 6 further indicate that supply chain network influences the environmental pillar. Once again, this effect appears positive and highly significant. Moreover, our results differentiate when we focus on the social pillar as we are unable to find a significant relationship, while the effect on governance pillar is moderately significant for the nodes component of the supply chain network. Overall, our results are consistent with our first hypothesis regarding the positive impact of the supply chain network on the ESG ratings. However, this impact does not appear to be always significant.

A plausible explanation for the positive and significant effect of the supply chain network on the ESG ratings can be explained as follows. A large supply chain network generates greater interconnectedness and communication among the members of this network and consequently information sharing (see Gualandris et al., 2021). In turn, this is expected to improve the distribution of resources, the innovation practices and consequently the firms' outcomes in terms of productivity and profits. This provides an incentive for firms to apply policies and initiatives via their operations that may have an increasing consideration for the environment and society. Such developments may have a significant impact on environmental, social and governance standards (for example, carbon emissions and waste, employee diversity, transparency with stakeholders). Overall, higher ESG standards could be associated with greater evaluation from investors who focus on firms that demonstrate long term sustainability development. In this regard, our results are in accordance with those reported by Koberg and Longoni (2019), Tamayo-Torres et al. (2019), Truant et al. (2023), and Das (2024) who highlight the important role of the supply chain network to influence ESG ratings.

It should be instructive at this point to mention that the environmental component of the ESG ratings is the main component which responds significantly to supply chain network impact. It appears that a large supply chain network mostly exerts an impact on the environmental pillar and thus the firms' environmental responsibility. This could be explained by the fact that minimum waste production, minimisation of carbon emissions, and lower greenhouse gas emissions among others environmental factors have a positive impact on the whole community as these factors represent global issues. More specifically, more (less) environmentally sustainable suppliers could enhance (damage) the credibility of firms. In addition to this, when cost-saving practices are adopted by suppliers (i.e., reduction in emissions), firms could also benefit in terms of cost savings. In turn, this generates a competitive advantage and hence improvements in sustainability performance.[1] In this regard, Dahlmann and Roehrich (2019) argue that the engagement of supply chain partners helps to address climate change.

[PLEASE INSERT Table 3 HERE]

4.2 The relationship between supply chain network and financial performance

Table 4 presents the results regarding the impact of supply chain network (either eigenvector centrality or nodes) and financial performance (Tobin's Q, stock returns, ROA, ROE, and ROS). We notice that the estimated coefficients mostly exhibit the anticipated positive signs (apart from Tobin's Q) and remain significant in columns 5 and 10 related to ROS. More specifically, the impact of eigenvector centrality (nodes) on ROS is highly (weakly) significant. We mention that our findings do not provide evidence of statistical significance to the remaining measures of financial performance. Overall, we provide empirical evidence supporting the second hypothesis of our study as the relationship under examination is positive apart from the Tobin's Q measure, while not always significant.

The significant relationship between a larger supply chain network and an increase in ROS may possibly be attributed to the operational efficiency generated by a large supply chain network. More specifically, operational efficiency involves the effective allocation of resources and delivery of firms' products to the right place, at the right time, and at the lowest cost keeping customers satisfied. Furthermore, operational efficiency implies a reduction in various types of costs such as inventory costs (via effective inventory management), production costs (via quicker order processing times) and transportation costs (via immediate delivery). This in turn implies that the volume of sales will be improved and consequently revenues as well as market share. In other words, the higher the ROS, the more profitable the firm, which has an impact on the overall performance of the firm. Our results are in line with other

[1]For more information, we refer the reader to US Environmental Protection Agency (EPA). The source of the information can be found on: https://www.epa.gov/climateleadership/supply-chain-guidance

related studies that have considered this relationship, such as the papers Dehning et al. (2007), Wagner et al. (2012), Wang and Sarkis (2013), Kim and Henderson (2015), Basole et al. (2017) and Luo et al. (2023), although different financial metrics are used.

In particular, Dehning et al. (2007) and Kim and Henderson (2015) are the studies that employ return on sales among other metrics and our results regarding this metric are in accordance. Furthermore, Wang and Sarkis (2013) employ return on assets and return on equity, which appeared insignificant in our study. Moreover, Wagner et al. (2012) use return on assets, while Basole et al. (2017) use return on assets, inventory over sales, and cost of goods sold over sales. Once again, we are unable to confirm a significant relationship related to the return on assets. Finally, Luo et al. (2023) employ stock returns for Chinese firms listed on the Shanghai and Shenzhen stock exchanges and our stock market metric is not supportive of a significant relationship. We summarise that all previous financial metrics contribute to profitability analysis and thus they add value to the firms' financial performance.

While a firms' financial performance could be attributed to some or all of the financial metrics mentioned above, it would also be interesting to look deeper into our results in order to justify the reasons why ROS responds significantly to a larger supply chain network compared with the other profit targets such as Tobin's Q, ROA, ROE, and firms' stock returns. To this end, it seems that the objective of a large supply chain network is to develop a competitive infrastructure related to the delivery of products from the suppliers to the point of sale. In turn, this creates value in all activities or minimises operating costs and consequently it generates efficient and effective management. The objective of efficiency is primarily captured by ROS which is considered as an indicator of both efficiency and profitability.

[PLEASE INSERT Table 4 HERE]

5 Robustness Checks

In this section, we analyse the robustness of our results. We examine whether our results alter when we split our sample between low and high polluting firms as well as between new and old companies. The rational is that high Greenhouse gas (GHG) firms are firms mainly from the manufacturing sector and therefore they are more supply chain depended. Low emission firms might be Financials and Health Care firms that their supply network might not be so important for the firms' operations. Also, older firms might have more established supply chain network and therefore it is easier for them to shift among suppliers. To split the sample we used the median (GHG) emissions scale by total assets. Similarly, we consider the median firm age of our sample, that is 21 years since their establishment.

Table 6 and Table 7 report the results for ESG and financial performance dependent variables, respectively. Also, panels A and B distinguish between low and high emission firms, while panels C and D between new and old firms. Both tables shows that are results are not sensitive to these two factors. Particularly, H1 is confirmed so that supply chain network increases firms' ESG scores, while H2 is not confirmed as supply chain does not affect financial performance.

[PLEASE INSERT Table 6 HERE]

[PLEASE INSERT Table 7 HERE]

6 Conclusion

In this study, we attempt to investigate the relationship between supply chain network approximated by either the eigenvector centrality or the number of nodes on the ESG ratings and financial performance. The ESG ratings refer to the environmental, social, and governance components. The financial performance includes the ROA, ROE, ROS, Tobin's Q, and firms' stock returns. We employ a panel data analysis model in which we include a set of control variables in order to capture the omitted variable bias issue. Our dataset covers the period from January 2005 to December 2021. On general principles, this study expands the existing literature in terms of investigating the impact of a large supply chain network on financial and non-financial metrics and thus we attempt to provide a more detailed and complete illustration of the relationships under examination.

Our findings are briefly summarised as follows. First, a large supply chain network has significantly and positively influenced the ESG ratings. This impact is more prevalent in the environmental pillar which implies the importance of more environmentally sustainable suppliers. Second, a large supply chain network appears to exert a positive and significant effect on return on sales. This implies that a density of supply chain networks mainly affects the financial performance via not only profitability but also efficiency.

Our findings raise certain policy implications for the industry, in particular. For example, focal firms need to understand the critical role of their supply chain network to achieve environmental benefits in terms of a low carbon footprint including the use of more environmentally friendly materials. Furthermore, focal firms having a large supply chain network could reduce operational costs via improvements in their efficiency. The adoption of such practices helps focal firms to generate value across the supply chain network and thus increase shareholder value, which all contribute to creating more sustainable prospects.

Future research may examine alternative proxies to capture financial performance such as return on investment or profit margin among others. In addition, the incorporation of countries other than the US such as Japan or the UK among others is another promising area. Finally, the examination of the relationship between supply chain network and greenhouse gas (GHG) emissions is another avenue for future research.

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Table 1: Sample Composition

Notes: This table shows the sample composition by (a) year and (b) sector. The Sector classification is based on GICS (Global Industry Classification Standard).

Year	**N. of Obs**	**Cum. N. of firms**	**Percent**
2005	288	288	1.78
2006	305	324	1.88
2007	337	373	2.08
2008	425	499	2.63
2009	450	571	2.78
2010	489	628	3.02
2011	499	666	3.08
2012	498	690	3.08
2013	544	726	3.36
2014	558	760	3.45
2015	934	1,147	5.77
2016	1,338	1,639	8.27
2017	1,640	2,041	10.13
2018	1,760	2,260	10.87
2019	1,950	2,547	12.05
2020	2,089	2,827	12.91
2021	2,080	3,028	12.85
GICS Sector	**N. of Obs**	**N. of firms**	**Percent**
10. Energy	1,053	179	6.51
15. Materials	1,105	148	6.83
20. Industrials	2,774	434	17.14
25. Consumer Discretionary	2,077	360	12.83
30. Consumer Staples	810	123	5
35. Health Care	2,029	545	12.54
40. Financials	2,229	487	13.77
45. Information Technology	2,052	398	12.68
50. Communication Services	624	112	3.86
55. Utilities	697	82	4.31
60. Real Estate	734	160	4.54
Total	16,184	3,028	100

Table 2: Descriptive Statistics

Variable	Obs	Mean	Median	St.Dev	Min	Max	Skew	Kurt
ESG	16184	40.627	37.223	19.248	0.44	95.162	0.491	2.401
E	16108	26.564	18.282	27.423	0	98.546	0.756	2.31
S	15129	42.685	39.461	20.964	0.629	98.011	0.437	2.393
G	14725	49.018	49.522	22.107	0.166	99.441	-0.046	2.083
EIGEN	16184	0.015	0.014	0.012	0	0.037	0.249	1.62
LN(NODES)	16184	5.257	5.916	2.106	0	8.232	-0.88	2.765
GENDER	16184	0.218	0.143	0.26	0	1	1.431	4.622
NATION	16184	0.499	0.5	0.357	0	1	0.04	1.672
EDUC	16184	0.267	0.2	0.277	0	1	1.055	3.436
EXP	16184	3.969	3.271	3.222	0	38.5	2.379	14.861
NETWORK	16184	3.355	2	3.856	0	51	2.767	19.345
BSIZE	16184	12.196	10	9.695	1	108	1.799	9.678
TOBIN	15451	1.427	1.001	1.236	0.238	7.422	2.725	11.5
IOWNER	16184	80.043	86.554	21.684	0	100	-1.47	4.862
LN(TA)	16099	8.128	8.114	1.832	0.44	15.136	0.055	3.413
INEF	13821	0.89	0.632	2.408	0	27.194	9.515	98.426
LIQUID	13634	0.35	0.253	0.424	0	6.514	7.129	85.07
LEV	15451	1.479	0.561	2.691	0.001	22.761	4.162	25.553
RETURN	14737	0.057	0.087	0.431	-1.853	1.585	-0.403	5.843
ROA	14107	0.268	0.246	0.235	-0.959	1.023	0.012	5.93
ROE	13989	0.293	0.21	0.363	-1.483	2.534	3.028	18.352
ROS	16098	74.827	60.263	65.705	0	334.356	1.507	5.747

Table 3: Main Results

Notes: This table summarises the coefficient estimates of the linear panel data model, outlined in Equation 3. All variables are described in Table 5. The sample period runs from 2005 to 2021. The cross section comprises a total of 3,028 companies that have available ESG score from REFINITIV, with a varying number of companies in each year. The model is estimated by means of fixed effects estimation methods. Robust standard errors are indicated in round parentheses. Asterisks ***, **, * denote the 1%, 5% and 10% levels of significance, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ESG	E	S	G	ESG	E	S	G
EIGEN	50.360***	124.709***	29.885	16.498				
	(17.028)	(23.180)	(20.106)	(29.336)				
LN(NODES)					0.262***	0.527***	0.149	0.279**
					(0.083)	(0.112)	(0.098)	(0.142)
GENDER	4.657***	4.236***	3.821***	5.001***	4.669***	4.249***	3.826***	4.972***
	(0.579)	(0.797)	(0.693)	(1.027)	(0.579)	(0.797)	(0.693)	(1.027)
NATION	-0.361	1.368**	0.874	-2.522***	-0.339	1.438**	0.887	-2.522***
	(0.502)	(0.692)	(0.600)	(0.889)	(0.502)	(0.692)	(0.600)	(0.889)
EDUC	2.368***	2.079***	2.473***	1.933**	2.395***	2.120***	2.489***	1.965**
	(0.539)	(0.736)	(0.638)	(0.933)	(0.539)	(0.737)	(0.639)	(0.933)
EXP	0.179***	0.148***	0.234***	0.076	0.178***	0.145***	0.233***	0.076
	(0.037)	(0.052)	(0.045)	(0.066)	(0.037)	(0.052)	(0.045)	(0.066)
NETWORK	-0.051	-0.044	-0.023	-0.093	-0.053	-0.050	-0.025	-0.093
	(0.044)	(0.060)	(0.052)	(0.075)	(0.044)	(0.060)	(0.052)	(0.075)
BSIZE	0.014	-0.017	0.056**	0.043	0.014	-0.016	0.056**	0.044
	(0.021)	(0.029)	(0.025)	(0.037)	(0.021)	(0.029)	(0.025)	(0.037)
TOBINQ	0.003	0.019	0.155	-0.216	-0.003	0.005	0.152	-0.224
	(0.131)	(0.177)	(0.154)	(0.223)	(0.131)	(0.177)	(0.154)	(0.223)
IOWNER	0.028***	-0.003	0.030***	0.051***	0.028***	-0.003	0.030***	0.052***
	(0.008)	(0.010)	(0.009)	(0.013)	(0.008)	(0.010)	(0.009)	(0.013)
LN(TA)	1.852***	3.015***	1.797***	1.107***	1.872***	3.079***	1.810***	1.083***
	(0.240)	(0.326)	(0.281)	(0.408)	(0.240)	(0.325)	(0.280)	(0.407)
INEF	-0.057	-0.008	-0.095	-0.018	-0.052	0.003	-0.093	-0.012
	(0.055)	(0.073)	(0.068)	(0.093)	(0.055)	(0.073)	(0.068)	(0.093)
LIQUID	0.246	0.026	0.499	-0.303	0.246	0.029	0.499	-0.314
	(0.280)	(0.387)	(0.333)	(0.477)	(0.280)	(0.387)	(0.333)	(0.477)
LEV	-0.304***	-0.262***	-0.327***	-0.256**	-0.304***	-0.261***	-0.328***	-0.257**
	(0.073)	(0.101)	(0.087)	(0.126)	(0.073)	(0.101)	(0.087)	(0.126)
CONS	0.085	-29.455***	3.554	22.680***	-0.733	-30.923***	3.094	21.557***
	(3.268)	(4.475)	(3.829)	(5.552)	(3.288)	(4.504)	(3.852)	(5.583)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Year × Industry FE	Y	Y	Y	Y	Y	Y	Y	Y
N	12,934	13,427	12,520	12,168	12,934	13,427	12,520	12,168
R2	0.092	0.109	0.093	0.047	0.093	0.108	0.094	0.049

Table 4: Financial Performance Results

Notes: This table summarises the coefficient estimates of the linear panel data model, outlined in Equation 3. All variables are described in Table 5. The sample period runs from 2005 to 2021. The cross section comprises a total of 3,028 companies that have available ESG score from REFINITIV, with a varying number of companies in each year. The model is estimated by means of fixed effects estimation methods. Robust standard errors are indicated in round parentheses. Asterisks ***, **, * denote the 1%, 5% and 10% levels of significance, respectively.

	(1) TOBIN	(2) RETURN	(3) ROA	(4) ROE	(5) ROS	(6) TOBIN	(7) RETURN	(8) ROA	(9) ROE	(10) ROS
EIGEN	-2.035	0.489	0.119	0.355	109.586***					
	(1.252)	(0.814)	(0.194)	(0.462)	(40.057)					
LN(NODES)						-0.001	0.004	0.001	-0.001	0.322*
						(0.006)	(0.004)	(0.001)	(0.002)	(0.195)
GENDER	0.016	-0.010	0.012*	0.001	1.093	0.015	-0.010	0.012*	0.001	1.135
	(0.043)	(0.028)	(0.007)	(0.016)	(1.369)	(0.043)	(0.028)	(0.007)	(0.016)	(1.369)
NATION	0.063*	0.043*	-0.003	-0.024*	-0.421	0.062*	0.043*	-0.003	-0.024*	-0.356
	(0.037)	(0.024)	(0.006)	(0.014)	(1.187)	(0.037)	(0.024)	(0.006)	(0.014)	(1.187)
EDUC	0.006	0.022	-0.005	-0.017	-1.576	0.006	0.022	-0.004	-0.017	-1.553
	(0.040)	(0.026)	(0.006)	(0.015)	(1.275)	(0.040)	(0.026)	(0.006)	(0.015)	(1.275)
EXP	-0.010***	-0.004**	0.000	0.003***	0.060	-0.010***	-0.004**	0.000	0.003***	0.056
	(0.003)	(0.002)	(0.000)	(0.001)	(0.089)	(0.003)	(0.002)	(0.000)	(0.001)	(0.089)
NETWORK	0.000	0.003	-0.000	-0.002**	0.114	0.000	0.003	-0.000	-0.002**	0.109
	(0.003)	(0.002)	(0.001)	(0.001)	(0.104)	(0.003)	(0.002)	(0.001)	(0.001)	(0.104)
BSIZE	-0.007***	-0.000	-0.000	0.002***	-0.021	-0.007***	-0.000	-0.000	0.002***	-0.021
	(0.002)	(0.001)	(0.000)	(0.001)	(0.050)	(0.002)	(0.001)	(0.000)	(0.001)	(0.050)
IOWNER	-0.001**	-0.001***	-0.000	-0.000	-0.008	-0.001**	-0.001***	-0.000	-0.000	-0.009
	(0.001)	(0.000)	(0.000)	(0.000)	(0.018)	(0.001)	(0.000)	(0.000)	(0.000)	(0.018)
LN(TA)	-0.318***	-0.258***	-0.048***	0.021***	-12.388***	-0.320***	-0.258***	-0.048***	0.021***	-12.308***
	(0.018)	(0.011)	(0.003)	(0.006)	(0.562)	(0.018)	(0.011)	(0.003)	(0.006)	(0.561)
INEF	-0.001	0.000	-0.006***	-0.001	-0.473***	-0.001	0.001	-0.006***	-0.001	-0.466***
	(0.004)	(0.003)	(0.001)	(0.001)	(0.129)	(0.004)	(0.003)	(0.001)	(0.001)	(0.129)
LIQUID	-0.056***	0.036***	-0.009***	-0.012	-2.069***	-0.056***	0.035***	-0.009***	-0.012	-2.062***
	(0.021)	(0.014)	(0.003)	(0.008)	(0.665)	(0.021)	(0.013)	(0.003)	(0.008)	(0.665)
LEV	-0.028***	0.091***	-0.001	0.043***	0.364**	-0.028***	0.091***	-0.001	0.043***	0.369**
	(0.005)	(0.004)	(0.001)	(0.002)	(0.173)	(0.005)	(0.004)	(0.001)	(0.002)	(0.173)
CONS	4.112***	1.169***	0.708***	0.226***	214.619***	4.102***	1.155***	0.702***	0.232***	213.973***
	(0.237)	(0.154)	(0.037)	(0.088)	(7.598)	(0.239)	(0.155)	(0.037)	(0.088)	(7.650)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year × Industry FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	12,725	12,769	12,695	12,689	12,769	12,725	12,769	12,695	12,689	12,769
R2	0.159	0.045	0.072	0.039	0.034	0.156	0.045	0.072	0.038	0.032

Table 5: Variable definitions

Notes: The figure shows the conceptual framework of the study with the relevant variables. The table describes the variables we use in our empirical analysis. The first column ("Variables") labels the variable. The second column "Definitions" describes the variable and explains how it is defined/computed/measured. The third column "Source" acknowledges the source of information.

Variables	Definitions	Source
	Panel A: Main variables	
ESG	ESG score is the weighted average score by the three pillars (E, S and G).	REFINITIV
E	Environmental score is the weighted average of resource use, emissions and innovation scores.	REFINITIV
S	Social score is the weighted average of workforce, human rights, community and product responsibility scores.	REFINITIV
G	Governance score is the weighted average of management, shareholders and the company's CSR scores.	REFINITIV
EIGEN	Supply chain Eigenvector centrality calculated as shown in Eq. (2). We use the Pairwise Vertical Relatedness Network data: Basic 10% Granularity Version.	Fresard-Hoberg-Phillips Vertical Relatedness Data Library
LN(NODES)	The natural logarithm of supply chain connections as shown in Eq. (1). We use the Pairwise Vertical Relatedness Network data: Basic 10% Granularity Version.	Fresard-Hoberg-Phillips Vertical Relatedness Data Library
	Panel B: Board variables	
GENDER	Percentage of female directors in the firm's board for any year given.	BoardEX
NATION	Percentage of firm's board members who are not Americans for any year given.	BoardEX
EDUC	Percentage of board members with either PHD or MBA in the board.	BoardEX
EXP	Average years of work experience in a board.	BoardEX
NETWORK	Number of board members siting in outside boards.	BoardEX
BSIZE	Number of directors sit in firm's board.	BoardEX
	Panel C: Financial variables	
TOBIN	This variable is calculated as (Equity market value + Liabilities book value) / (Equity book value + Liabilities book value). It measures market value of the company's equity capital.	Compustat
IOWNER	Percentage of institutional owners for any year given.	REFINITIV
LN(TA)	The size of the firm is proxied by the natural logarithm of firm's total assets.	Compustat
INEF	Inefficiency is calculated as the ratio of total cost of goods to total sales.	Compustat

LIQUID	Liquidity is calculated as the ratio of current assets to current liability. It measures the company's liquidity ratio.	Compustat
LEV	Leverage is the total debt to total equity the firm. It is a proxy for firm risk.	Compustat
RETURN	The stock return is measured as the logarithmic difference between the price of a stock at year t to $t-1$.	Compustat
ROA	Return on assets is the ratio of net income to total assets. It shows firm profitability in relation to total assets.	Compustat
ROE	Return on equity is the ratio of net income to shareholders' equity. It shows firm profitability in relation to equity value.	Compustat
ROS	Return on sales is the ratio of EBIT to sales. It shows operating efficiency.	Compustat

Table 6: Robustness Checks on ESG

Notes: This table summarises the coefficient estimates of the linear panel data model, outlined in Equation 3. All variables are described in Table 5. The sample period runs from 2005 to 2021. The cross section comprises a total of 3,028 companies that have available ESG score from REFINITIV, with a varying number of companies in each year. The model is estimated by means of fixed effects estimation methods. Robust standard errors are indicated in round parentheses. Asterisks ***, **, * denote the 1%, 5% and 10% levels of significance, respectively.

	(1) ESG	(2) E	(3) S	(4) G	(5) ESG	(6) E	(7) S	(8) G
				Panel A: Low GHG Emission firms				
EIGEN	48.407*	149.643***	72.396**	-36.368				
	(27.858)	(40.514)	(33.143)	(48.203)				
LN(NODES)					0.213*	0.602***	0.255*	0.013
					(0.119)	(0.172)	(0.141)	(0.206)
All controls	Y	Y	Y	Y	Y	Y	Y	Y
N	4821	5056	4664	4531	4821	5056	4664	4531
R2	0.096	0.123	0.069	0.080	0.096	0.120	0.069	0.082
				Panel B: High GHG Emission firms				
EIGEN	103.221***	126.983***	83.198**	61.544				
	(29.965)	(40.371)	(36.062)	(50.627)				
LN(NODES)					0.656***	0.741***	0.680***	0.260
					(0.199)	(0.268)	(0.238)	(0.333)
All controls	Y	Y	Y	Y	Y	Y	Y	Y
N	4725	4852	4583	4416	4725	4852	4583	4416
R2	0.025	0.163	0.015	0.018	0.027	0.166	0.014	0.020
				Panel C: Newly established firms				
EIGEN	37.562	147.560***	30.636	-23.354				
	(25.098)	(33.559)	(29.275)	(43.426)				
LN(NODES)					0.234**	0.469***	0.079	0.216
					(0.117)	(0.155)	(0.135)	(0.200)
All controls	Y	Y	Y	Y	Y	Y	Y	Y
N	6072	6433	5901	5977	6072	6433	5901	5977
R2	0.072	0.023	0.069	0.065	0.072	0.019	0.069	0.071
				Panel D: Mature firms				
EIGEN	67.855***	98.764***	45.894	23.754				
	(24.047)	(33.099)	(28.958)	(42.320)				
LN(NODES)					0.458***	0.540***	0.395***	0.426**
					(0.124)	(0.171)	(0.150)	(0.217)
All controls	Y	Y	Y	Y	Y	Y	Y	Y
N	6571	6691	6331	5921	6571	6691	6331	5921
R2	0.046	0.178	0.058	0.006	0.049	0.182	0.058	0.006

Table 7: Robustness Checks on Financial Performance

Notes: This table summarises the coefficient estimates of the linear panel data model, outlined in Equation 3. All variables are described in Table 5. The sample period runs from 2005 to 2021. The cross section comprises a total of 3,028 companies that have available ESG score from REFINITIV, with a varying number of companies in each year. The model is estimated by means of fixed effects estimation methods. Robust standard errors are indicated in round parentheses. Asterisks ***, **, * denote the 1%, 5% and 10% levels of significance, respectively.

	(1) TOBIN	(2) RETURN	(3) ROA	(4) ROE	(5) ROS	(6) TOBIN	(7) RETURN	(8) ROA	(9) ROE	(10) ROS
					Panel A: Low GHG Emission firms					
EIGEN	-0.256	0.592	0.522	0.188	142.033***					
	(2.637)	(1.452)	(0.350)	(0.611)	(54.375)					
LN(NODES)						0.008	0.006	0.002	-0.002	0.412*
						(0.011)	(0.006)	(0.001)	(0.003)	(0.233)
All controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	4797	4821	4775	4772	4821	4797	4821	4775	4772	4821
R2	0.082	0.034	0.006	0.022	0.002	0.080	0.034	0.006	0.021	0.002
					Panel B: High GHG Emission firms					
EIGEN	-3.382**	0.624	0.152	0.362	252.983***					
	(1.468)	(1.197)	(0.259)	(0.775)	(68.671)					
LN(NODES)						-0.027***	0.002	-0.001	0.006	0.936**
						(0.010)	(0.008)	(0.002)	(0.005)	(0.457)
All controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	4717	4725	4721	4720	4725	4717	4725	4721	4720	4725
R2	0.043	0.079	0.238	0.021	0.132	0.045	0.080	0.243	0.019	0.131
					Panel C: Newly established firms					
EIGEN	-3.533*	1.891	0.288	1.007	186.734***					
	(2.118)	(1.426)	(0.343)	(0.779)	(65.338)					
LN(NODES)						-0.009	0.010	0.003**	0.000	0.618**
						(0.010)	(0.007)	(0.002)	(0.004)	(0.303)
All controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	5990	6015	5978	5976	6014	5990	6015	5978	5976	6014
R2	0.239	0.043	0.082	0.021	0.030	0.236	0.043	0.084	0.018	0.026
					Panel D: Mature firms					
EIGEN	0.112	-0.176	-0.035	-0.455	75.591					
	(1.551)	(1.024)	(0.238)	(0.604)	(53.403)					
LN(NODES)						0.011	0.003	-0.001	-0.006**	0.053
						(0.008)	(0.005)	(0.001)	(0.003)	(0.275)
All controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
N	6446	6465	6431	6427	6466	6446	6465	6431	6427	6466
R2	0.099	0.046	0.067	0.028	0.050	0.096	0.047	0.068	0.029	0.049