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Effective multi-tier supply chain management for sustainability

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Abstract

Sustainability issues pervade the supply chain deep into the recesses of various global regions and resources. Supply chains can become quite complex as they form multiple tiers of organizations and across networks. Solving anthropocentric pressures on the environment and human society means compelling supply chains to alleviate their environmental and social burdens. The strategic and operational complexities of multi-tier supply chain sustainability are transcendent. Addressing these concerns is still in its relative infancy amongst business, engineering, and production economics solutions. It is within this environment that this special issue in the *International Journal of Production Economics* advances this important research stream. Twenty-three articles using multiple methodologies, theories, and developments provide insights, clarifications and potential solutions to some of the most pernicious problems of multi-tier sustainable supply chains. This editorial overviews the various contentions and study interrelationships, whilst providing some future research directions.

Keywords: Sustainability, Multi-tier Supply Chains, Environmental, Operations Research and Management, Editorial

It has become more common and accepted knowledge that for organizations to remain competitive, and in some cases to survive, a proper balance of economic, environmental and social dimensions needs to be managed in their global operations (Kwon and Lee, 2019; Sarkis and Zhu, 2018). This triple-bottom-line perspective is central to organizational sustainability strategy and operations (Sarkis and Dhavale, 2015). Sustainability strategies and practices require radical change in how organizations are managed (Soderstrom and Weber, 2019). Expanding sustainability across the supply chain has required additional evolutionary, and potentially revolutionary, innovation and practice (Jadhav et al., 2018).

This challenge of achieving sustainability is even more profound in the case of cross-tier and multi-tier supply chains (Koh et al, 2012); and it has been demonstrated to be highly complex when social, environment, economic, and also health, dimensions are considered together in

a circular resource framework (Koh et al, 2017) especially in electronic waste recycling (Awasthi et al, 2019; Cucchiella et al., 2015).

Mathematical models and solution methods have provided the tools for solving a vast array of traditional supply chain management problems. Sustainability provides greater and new challenges; where problems have become more complex and difficult to solve (Bai and Sarkis, 2018; Santibanez-Gonzalez et al. 2018). Integration and coordination of different supply chain actors can play an important role in balancing and reducing sustainability impacts (Zissis et al., 2018). A critical and under-investigated aspect of sustainable supply chains, providing the greatest potential for environmental and social sustainability influence, is the multiple-tier or multi-tier supply chain (Dou et al., 2018; Sauer and Seuring, 2018). Supply chain studies that go well beyond the typical dyadic -- buyer-supplier relationship -- are needed to further penetrate the supply chain and expand theoretical and practical study boundaries.

This expansion of scope means that organizations have to effectively work with more than one tier and triad -- joint multiple suppliers and focal organizations -- to solve sustainability problems. As the expansion of scope occurs, the relative sphere of influence (Hall, 2006) rises. When parties are legitimately in charge of sustainability management, transformation becomes an issue. Sustainability transformation requires further alteration of current institutional norms to embrace a sustainability philosophy across many supply chain tiers (Grimm et al., 2016).

This broader multi-tier focus is particularly important, as organizational oversight progresses downstream in the supply chain; where a single partner organization with poor sustainability performance could potentially compromise the reputation of other participating multi-tier supply chain partner organizations. A challenge to supply chain legitimacy may arise due to poor sustainability performers hidden deep in the supply chain.

Here is another exemplar. The automotive industry is facing great challenges in environmental concerns. A single organizational failure can cause reputational issues across multiple organizations in the same industry. The case of Volkswagen and its fraudulent diesel emissions scandal (Siano, et al., 2017) is one such situation. It is not just a linear vertical set

of relationships in the multi-tier relationship that is of concern, but horizontal relationships as well. There exists a network or web of linkages. Multidimensional relationship concerns are difficult to manage and require investigation.

In this efflorescent setting practitioners and academics are aware of the need for a novel and improved set of approaches that integrate mathematical models and solution methods to address a wide variety of sustainable supply chain management concerns (Santibanez-Gonzalez et al, 2018).

Given this emergent setting, we sent out a challenge to scholars from operations and supply chain management, management sciences, operations research, economics and other disciplines. This challenge requests greater investigation and study, revisiting and enhancing traditional strategic, tactical, and operational study areas to address issues arising within the management of the multi-tier (extended) supply chain. Our goal was generation of a new and extended body of knowledge able to address sustainability issues in multi-tier supply chain systems.

A vast body of existing sustainability-oriented literature investigates relationships between stand-alone organizations and their direct suppliers or customers. In fact, a recent tertiary literature review on sustainable supply chains (Martins and Pato, 2019), found 198 literature review papers on the topic of sustainable supply chains. However, research on the evaluation of supplier sustainability performance and coordination practices beyond the traditional tier-1 level, or dyad, are relatively scarce.

Organizations seeking to address suppliers beyond the tier-1 level face several unique challenges not addressed by traditional supply chain management. For example, in a traditional supply chain management setting, a single organization has a direct contractual relationship with its tier-1 suppliers (and clients). This lack of a formal contractual relationship with tier-(1+n) makes it difficult for the focal organization put direct pressure on the suppliers of the suppliers. Many times a focal organization does not even know its sub-supplier. Usually a focal organization relies on its direct supplier's willingness to disclose sub-suppliers and to manage the dependent relationship. Many times, in sub-supplier management, a third party is used. For the case of sustainability in the supply chain this third-

party is a non-governmental organization (NGO) (Grimm, et al., 2014) that might acquire data for industry or supply chain use. Sometimes the third party is a consulting organization used for supplier network management.

Researchers also face methodological difficulties that do not pertain to direct supplier relationships. In empirical survey based research, it is difficult to design studies and complete statistical analyses that can fully incorporate multiple tiers of organizations in supply chains. In some mathematical modeling approaches, such as game theory, the inclusion of multiple tiers for investigation makes for very complex mathematical problems to solve and, in some cases, could become mathematically intractable (Santibanez-Gonzalez and Diabat, 2016). The complexities of establishing a networked supply chain simulation requires significant simplification. There is a need to develop new methodologies, metrics, tools, and research designs to address these complexities that arise in real problems.

Many approaches for managing the supply chain assume a controlling body exists to control strategic and tactical decisions along the supply chain. Having this overarching focal organization with power disregards a multiple-organizational nature and potential conflicts of interest. Issues of coopetition may also arise. Coopetition focuses on how organizations that are used to competing will form alliances to help solve broader sustainability (e.g. industry) problems (Havezalkotob, 2017). How do companies manage these multiple alliances or sub-tier supply chain competition concerns? What information and insights can be gleaned from modeling and analytical approaches that address these concerns?

There is a need to extend thought and go beyond traditional dyadic modeling efforts, to develop new mathematical models and solution methods to handle the computational complexity of these new multi-tier supply chain management problems. Solution techniques that can manage the balances, tradeoffs, and synergies associated with the integration of economics, environment and social perspectives into the traditional supply chain decision making processes are also requirements.

The objective of this special issue is to compile innovative and novel research on modeling and solution approaches that integrate analytical models and solution methods to generate a fresh body of knowledge to assist managers and decision-makers in the management of multi-

tier supply chains for sustainability. Solution approaches were built upon management science, operational research, computer science, applied mathematics and statistical concepts and tools.

We challenged and encouraged our research community to modify, expand present theories, and to develop with rigor a new body of knowledge; knowledge that contributes to mitigate change environmental degradation through the effective management of multi-tier supply chains for sustainability. We received many high-quality papers; papers that examined emerging practices, new concepts, or developed and enhances current theory.

The Special Issue

This special issue includes 23 papers. A summary and paper order appears in Table 1. The order and grouping of papers is guided by methodological approach. Although some papers may fit into more than one category, we provide a categorization by what we feel is the major focus. Initially -- before introducing some overviews of the special issue publication -- we provide a summary of the topical coverage by contribution based on the sustainability concern, predominant methodology used, the empirics or data informing the study, and the number of supplier tiers in the study.

Table 1 about here

Sustainability Focus

In table 1 we begin with some paper categorizations on the type of sustainability issue the study addresses. In almost every case, economic sustainability is a primary criteria given most models used typically focus on cost minimization or profit maximization. Businesses and supply chains still assume that economic sustainability as a starting point. The term sustainability has achieved a broader status. It initially had a consensus primary focus on environmental issues; environmental goals were prevalent concerns. Interestingly, as the term sustainability has matured in the academic literature, greening and environmentalism has seen arguably and paradoxically less relative emphasis (Sarkis, 2007).

There are a number of variations in the sustainability focus in the papers in this special issue. Some of the papers just cover general sustainability, which represents the three dimensions considered simultaneously. The topic that seems to have some of the greatest attention in the multi-tier supply chain research in this special issue focuses on recycling and solid waste concerns. Circular economic, reverse logistics, extended producer responsibility, and end-of-life, aspects of sustainable supply chain management drive this focus. In many ways the reverse logistics and closing-the-loop considerations, due to their relative immaturity, require multiple partners to manage. Reverse logistics also typically means discrete, durable products that contribute to solid waste management aspects (Lai et al., 2013).

Interestingly, one of the current major broad-based environmentally oriented issues, although represented, is not a primary focus for most of the special issue papers. Climate change -- typically represented through management of carbon or greenhouse emissions -- is a primary focus for only three of the papers. Although the issue may represent an element of pollution emissions, especially air emissions, and multiple sustainability metrics; it is not necessarily the explicit focus of these studies.

As a stand-alone issue, social sustainability is underrepresented and mathematical models that consider social issues remain understudied (Santibanez Gonzalez et al., 2015, 2018). Social relationships and social sustainability are a focus of two papers. Although social sustainability is covered in the three general sustainability papers from this special issue. The preponderance of papers have some aspect of greening or environmental sustainability included. Historically the sustainable supply chain literature has underplayed social sustainability and focused primarily on environmental and economic sustainability (Martins and Pato, 2019). Given that this special issue has encouraged quantitative and analytical modeling, the difficulties of objective quantification and monetization of social issues likely limited the number of social sustainability focused papers.

Methodology

The special issue call charged the community to provide us with analytical and quantitative modeling investigation and advances. We also encouraged qualitative and broader empirical studies. Given the audience and majority of papers within the *International Journal of*

Production Economics are analytical and quantitatively focused, it is not surprising that most of the contributions in this special issue are also of this variety. In terms of the categorization and content of articles we grouped them based on type of methodology, beginning with more qualitative contributions evolving to more analytically focused manuscripts.

We begin with a literature review and case study set of papers for the special issue. Although case studies may be relatively qualitative, many have quantitative and analytical characteristics. In terms of methodology, at this time, it is probably more effective for qualitative and case study investigations given the nature and complexity of multi-tier sustainable supply chain research. Also, given the relative novelty of this topic exploratory type research, represented by many case study and qualitative works, is likely. Even Delphi studies, which utilize subjective opinion to evaluate the field, still rely on some statistical modeling.

In empirical studies, broad based data either through primary or secondary data collection, is usually referred to as quantitative research in the social sciences. Although, in the analytic and operations research community these methodologies are considered closer to the qualitative end of the methodological spectrum. Many of these methodologies rely on regression and correlative approaches, typically econometric modelling, to evaluate theories and hypotheses. In this special issue we have three papers using various correlative approaches including one of each in multiple regression, hierarchical regression, and structural equation modeling.

The studies we primarily categorize as quantitative begin with identification and use of indicators for multi-tier supply chains. In both papers, multiple indicators are developed for various aspects of managing multi-tier supply chains. These indicators are necessary for multiple purposes and are typically quantitatively aggregated and developed. Given that there are multiple indicators, whether ecological or general sustainability, our next set of papers would include formal analytical, sometimes defined as soft-computing, models that can evaluate multiple criteria. The two papers using these methodologies adopt fuzzy multiple criteria approaches.

The largest set of papers, seven, utilize economic game theoretic modeling approaches. A variety of game theoretic models, each with a differing focus appear in this special issue. The type of game theoretic perspective differs and some of these are delineated later. Clearly, in almost every case economic and environmental factors are considered. None of the models consider social issues. Although multiple tiers of the supply chain are considered, which add complexity to the game theory models, the methodology provides ample opportunity for multiple investigations. In each case the reader will find an interesting and differing nuance. The solution methodologies and structures also vary; for example, some use mathematical programming while others utilize continuous numerical optimization.

More traditional optimization, mathematical linear and non-linear programming are represented in the next set of methodologies. Although mathematical programming is used in some of the game theory and data envelopment analysis (DEA) models, those that develop new formulations and use mathematical programming are categorized into this group. In some cases, the solution method may be a methodological contribution. The last methodological study utilizes system dynamics, jointly with DEA. This paper is characterized as a multi-methodological paper. It is surprising that in our quantitative modeling papers few multi-methodology techniques were integrated to solve problems; given that many recent works utilize joint methodological approaches especially those studies adopting multiple criteria analyses.

Empirics and Data

The type of methodology plays a role in the types of empirical data, if any, is used in an investigation. The papers in this study are not an exception; and follow similar patterns to empirical evaluation and/or data situation.

Literature reviews usually utilize data from journal and index databases such as Scopus or even Google Scholar. The approach used in terms of data management and manipulation may range from simple counts, to citation analysis, to content analysis. Bibliometrics play a significant role in these approaches. The only major literature review in this special issue utilizes publication content and some frequency analysis.

Qualitative information and coding is completed for the three case study papers. But not all case study information is qualitative. For example, quantitative case study, primary data, is utilized for the game theoretic analyses. Field study information for some of the multiple criteria works may also be considered case study empirics, where direct decision maker or organizational information is used for the tools. This situation exists in at least two of the papers for this special issue.

Secondary archival data appears flexibly across a variety of methodologies. Secondary archival data may derive from different publicly or privately available databases. Government or private agencies acquire or develop this data. As an example, pollution emissions databases exist broadly across a variety and types of emissions including hazardous waste such as the Toxics Releases Inventory (TRI) database or energy usage or air emissions (Sarkis, 2017). Private archival data may derive from a number of sources and including companies that offer this service such as Trucost and KLD (Delmas et al., 2013). In this special issue archival data derives from government, private databases such as the Carbon Disclosure Project (CDP) and Thomson Reuters ESG database, corporate reports, and publically available journal ranking data.

Survey based and industry data is primary empirical data collection from a broader set of sources. This data acquisition is usually completed by selecting a random or convenient sample of a population. Usually this data type is evaluated using multivariate regression or econometric techniques. In these cases the data is gathered through traditional or web-based surveys. Typically most of the studies using this approach will have difficulty getting a full appraisal of a multi-tier supply chain because data acquisition is usually from a key informant and their practices. It is difficult to apply such techniques when there are multiple players in various positions in a supply chain. New techniques for gathering and analyzing survey based data is needed. Two papers have provided some results from this type of data collection in this special issue.

The most common form of data utilized in this special, unsurprisingly, is simulated data. Acquiring organizational environmental and social sustainability data, especially across multiple tiers of a supply chain, is difficult. Also given that the preponderance of methodologies are quantitative and analytical modeling, the focus is less on the data and more

on methodological and analytical results. Some simulated data is based on actual practical information and some relies on varying select parameters. But even with simulated data research propositions and theoretical insights on relationships can be made. Having actual data to help support the analytics through actual observation is a powerful triangulation of the research results.

Supply Chain Tiers

One other characteristic for grouping papers is by the number of tiers in a study. The results show that although we stipulated multi-tier we did not eliminate any works that considered at least a dyadic situation, two-tiers. The spirit of the special issue is to focus on three or more tiers and this is evidenced with most of the articles focusing on at least three tiers.

Three tiers, a triad, can be represented by a focal organization, its supplier level, and its customer level. In some ways this is the most basic elemental supply chain that can have traditional operations, purchasing/procurement, and marketing and sales management activities. Triads may be a network or a linear set of tiers, and can include open, transitional, and closed triads (Mena et al., 2013); which represent lessened to greater interactions amongst various tiers of the supply chain.

Another set of papers considers even a greater number of tiers, although some are not explicitly modeled, but only suggested implicitly. Whether it is modeling, empirical work, or expert opinion, the greater the depth the more difficulty in evaluation. Some of the multi-tier, multi-echelon papers do try to simplify by considering a sub-set of potential factors for consideration. We also have the opportunity, in this special issue, to see how a broader multi-tier network with complex interactions are modeled and evaluated. Some tools are capable of evaluating networks; the network articles are all based on formal analytical modeling approaches.

Some of the papers introduced a comparative analysis of multiple industrial multi-tier chains to evaluate if there are differences. The number of tiers varies in some of these situations. We categorize those as multiple industry multi-tier evaluations. We did not explicitly consider categorizing the industry focus and type for each article, but some of the industrial

characterizations are briefly described in our overview of the contributions to the special issue.

We now provide an overview of the special issue by highlighting study contents as an introduction for the reader.

Special Issue Contributions

The special issue papers commence with an overview of the multi-tier sustainable supply chain field. Jabbour et al., (2019) provide an overview and synthesis of the field through a review of 43 identified articles with quantitative modeling as their underlying approaches. Given that there are 23 articles in this special issue, a majority of them – 18 are primarily analytical or quantitative methodologies or investigations – this volume of review papers by Jabbour et al. (2019), exemplifies the immaturity of the field. In their outcomes they identify 16 major research gaps, a relatively fertile series of directions for future research streams. They also provide an interesting synthesis framework that places these research gaps graphically. Implicitly this framework is also showing that multiple interrelationships also exist for joint studies and influences of these research gaps. This review paper confirms our initial beliefs that this topic requires significant research and advancement; one that is underrepresented in the supply chain and sustainability literature.

Digging deeper into the multi-tier supply chain typically takes researchers and organizations into some of the most sustainably sensitive organizations and processes. The primary industry and operations that exist at the far upstream activities are the extractive industries; mining, petroleum and farming industries are examples. Of these industries, some of the most influential in a region -- ones that can influence a region for geological epochs -- are in mining (Kusi-Sarpong et al., 2016).

In mining mountains may be made into valleys, whole indigenous populations relocated, biodiversity of regions and ecosystems permanently damaged; all of these occurring in emerging economy nations who have limited opportunity or motivation to respond.

Investigating how these industries, if they can, can become more sustainable is central to overall sustainability of supply chains (Canales et al. 2017; Pimentel et al., 2015).

Digging deep into the minerals supply chain is what Sauer and Seuring (2019) attempt in their investigation. They make an important observation that a vast majority of their identified sustainability concerns need to be addressed deep in the supply chain, sometimes nine tiers deep from a retail or OEM focal organization. Many of these activities and organizations, they argue, lie well outside the current core research and practice of multi-tier sustainable supply chains. They observe that Schmidt et al.'s (2017) supply chain position paradox tends to occur. This paradox states that organizations at the downstream end – retailers, for example – have less impact by their green supply chain practices, then those organizations further upstream – mining – who have higher impacts from their fewer green practices. Although not mentioned in the paradox discussion, Sauer and Seuring point to another paradox. This paradox is the issue of the most sensitive sustainable supply chain members, deep in the upstream, are hidden from the greatest stakeholder pressures that appear in the downstream locations. Eventually, Sauer and Seuring recommend various structures to help address many of the issues identified by their Delphi study.

The complexity of managing multi-tier sustainable supply chains becomes more evident in the study by Jia et al., (2019). Using a case study approach, they delve into how multinational corporations (MNCs) are able to manage their multi-tier supply chains, especially those, and many do, that go deep into emerging economy nations. They investigate the interactions between supply chain leadership, governance, structure and learning. They extend each of these interactions beyond the traditional dyadic relationship. They utilized an NGO -- the World Wildlife Foundation (WWF) -- to help them attract MNCs for investigation. Three large Western organizations, primarily headquartered in Europe were selected. Each organization has had a reputation and strategic goal for building sustainability along their supply chains; interestingly some are upstream, some would be considered downstream with recycling type companies. They used various categorizations of multi-tier supply chains based on closed-loop status and triadic relationships, for example. This issue exemplifies how to not only structure designs, but also label variations in multi-tier or multi-alliance supplier relationships. For example, the issue of coopetition may arise in some situations.

Overall, they introduce a number of propositions relating the four major elements, these relationship and proposition summaries appear in their Figure 3. One important point, and there are many more, is the amount of contingencies that may exist in the relationships. This finding is unsurprising given that different industries, leadership styles, and modes of governance, all part of contingency theory, have shown this situation to be true for many types of organizational and alliance studies. The sustainable multi-tier supply chain is no exception; the variations can be even larger as the complexities of the relationships increase.

One of the characteristics that can define an article in this special issue is the theoretical perspective of the study. Organizational and supply chain theory applications are growing, especially in the sustainable supply chain literature (e.g. see Sarkis et al., 2011). Lechler et al. (2019) evaluate how organizations collaborate with sustainability assessment sharing strategic alliances for multi-tier supply chains. In this case they utilize an extended agency theory perspective. Agency and many other organizational theories are typically utilized to evaluate a single organization's situation. Extending organizational theories to the supply chain level of analysis has been a goal in many research streams. In this situation the role of the principal and the agent shifts, where a third party alliance organization, serves as an auditor or management agency related to members of a supply chain. The idea of utilizing a third-party to dig deep into the supply chain and observe or manage sustainability has been occurring through various labelling and sustainability standards mechanisms. Sustainable supply chain alliance formation within an industry or product environment can improve efficiencies in managing sustainability; for example textiles and the electronics industries have formed and supported third-party groups to manage environmental and social sustainability standards for their industries. A series of six sets of propositions are developed in this exploratory research. An extended research framework, defined in some literature as 'middle-range theory' (Carter and Rogers, 2008) is an ultimate outcome; middle-range theory is a step towards development of more formalized theory. As evidenced by this and other articles, much of the research is exploratory due to immaturity of the field. The framework also contributes by showing how to partake, develop, and benefit from involvement in these alliances.

Third-party assessment can occur with strategic, long term industry alliances, or shorter-term one-off evaluations. In strategic relationships, agency theory might be an appropriate theoretical lens, as in the previous special issue paper by Lechler et al. (2019). Sometimes these third parties do not necessarily require strategic alliances, but only some form of certificate that the supplier met sustainability standards. In this broader sense, information processing theory, according to our next paper by Hannibal and Kauppi (2019), is an appropriate theoretical lens. Typically information and knowledge at sub-tier suppliers is not clear and an information asymmetry exists. The basic research question is whether third party assessment can act as a bridging mechanism across tiers by supplying information to reduce information asymmetry. Essentially, this is similar in concept to whether closed triads can extend to closed n-tier supply chains. A broad set of products, and industries, were evaluated in the qualitative study. The evaluation of the studies was completed using an information processing activity framework. Interestingly, their finding supports the third-party less as an operational 'one-off' relationship, but more as a strategic alliance collaborator, as espoused by the previous article. Although no specific research propositions were developed, this study strengthens the case that third-party partnering is necessary for effective multi-tier sustainability management of supply chains.

Similar to the previous article (Hannibal and Kauppi, 2019) in this special issue, the special issue's next paper (Gong et al., 2019) faces concerns with information and its role in sustainable supply chain management. Information exchange, especially customer awareness, plays a role in supplier sustainability performance and its diffusion. Engagement by stakeholders and focal organization sustainability capabilities, which borrow from stakeholder theory and resource based view theoretical perspectives, play mediating and moderating roles, across the relationships. The authors examine external and internal relationships and capabilities to argue for eventual superior sustainable supply chain performance. This perspective is also investigated in a later paper by Jadhav et al. (2019) who consider internal versus external relationships as a supply chain orientation.

Customers, the focal organization, and broader supply chain sustainability performance represent the multi-tier affects. They further argue that improved sustainability practice diffusion is more likely as the capabilities of an organization increase. There is an implication

that diffusion of sustainability practices throughout multiple tiers of supply chains is only as strong as their weakest link; or at least a bottleneck can occur if a very powerful focal organization has minimal sustainability capabilities. But, fortunately for sustainability proponents, in a networked supply chain various diffusion supply chain paths do exist.

Collaboration plays a large role in close and strategic supply chain relationships. But, Um and Kim (2019) argue that not all collaborations, as typically hypothesized, lead to good performance; this is especially true for sustainability. Similar to many articles in this special issue, information sharing plays a significant collaboration support mechanism; as do a number of other collaboration characteristics. Information sharing can also lead to various opportunistic behaviors resulting in distrust. The authors argue that having appropriate governance mechanisms in place can help address these concerns. The authors draw on a variety of popular theories to help support their various hypotheses which are tested econometrically. Some of the most popular theories in organizational and supply chain management theories including transaction cost economics, relational and resource based views are drawn upon to investigate a series of relationships. The authors also add in social exchange theory to help develop some of their hypotheses. Overall, six hypotheses, some focusing on direct, some on moderating relationships, are evaluated. Most of the relationships are supported. The only hypothesis not supported is the role of governance in moderating collaboration and organizational performance. Although the direct relationship is supported. Overall, there exist a series of complex relationships supporting the situation where governance mechanisms need to be in place for organizational performance to increase the strength of direct relationships. The question that needs to be answered is whether non-economic sustainability performance also exists in these situations. Given this paper's focus on cost, it is not clear whether these relationships hold for more pure general sustainability collaborations, transactions, and performance. Governance can be further studied in the broader sustainability perspective. Governance mechanisms, especially more formalized, contractual ones, may not exist throughout a multi-tier supply chain, spanning sub-suppliers; their characterizations need investigation.

The internal versus external focus of sustainability practices, coordination and collaboration, unlike integrated supply chains, has been defined as supply chain orientation by some of the

literature (Jadhav et al., 2019). This internal-external relationship has been central to sequencing sustainable supply chain practices in addition to determining the relative influence (Zhu et al., 2012; 2013). In a series of hypotheses, the paper argues that coordination and communication play a role in both internal and external social and environmental sustainability practices adoption. They also posit one of the arguments made in the literature – and by Hannibal and Kauupi (2019) in this special issue – that a focal organization has to 'get their house in-order' before focusing on external activities. They find that this relationship holds for environmental issues, but not necessarily for social sustainability concerns. They find this counter-intuitive and important finding and make the observation that it exists. It may be that the knowledge and expertise in internal environmental practices are more advanced than social practices and thus it is easier to monitor and build external environmental sustainability practices. Additionally, some environmental aspects are easier to identify, measure and manage, while social sustainability tend to be less tangible. But variations in relationships with social and environmental supply chain sustainability have been shown to exist in the literature (e.g. Wang and Sarkis, 2013). This article (Jadhav et al., 2019) did not specify the number of tiers in sustainable supply chain practices and could probably have meant dyadic or greater relationships that needed to be managed. Also, although they did separate the external practices into environmental and social, they did not do this for internal situations and could have resulted in variations in their results; which is left for further research.

Most of the earlier papers in this issue have considered descriptive analyses for multi-tier sustainability supply chains. As the approaches evolve to more analytical approaches prescriptive perspectives emerge – although not all the remaining papers are necessarily prescriptive or normative. An example of this evolution is the next two papers that focus on development of indicators for multi-tier supply chains. The first of these two papers is by Tuni and Rentizelas (2019).

Tuni and Rentizelas (2019) introduce a four stage methodology with the core aspect a new recursive mechanism to identify a supply chain's eco-intensity and the environmental 'backpack' of products. Their eco-indicator incorporates both environmental and economic values, where economic valuation is used as a denominator to determine the total impact on

unit cost. Product volumes are then utilized to infer eco-intensity of products that flow through a supply chain. An example using carbon emissions and water consumption is provided. The basic advantage of this technique is that it considers the supply chain partners as disparate and individual entities who wish to protect their own organizational information. They utilize a more indirect triadic or multi-tier relationship as the basis of their recursive technique. Given that many relationships in the supply chain are transactional, and not necessarily strategic, the authors argue that an eco-indicator that can capture information in both these environments is valuable. Information transparency and sharing, as espoused by some of the previous studies in this special issue, do not necessarily have to play an important role. Life cycle assessment (LCA) is part of the underlying foundation of the technique as well. The applications of this multi-tier supply chain eco-indicator can range from benchmarking of supply chains and products to each other, or as performance measures that can be used for broader empirical research studies. Even in this situation, some information on broader organization environmental performance needs to be accessible to users of the ecological indicators.

While Tuni and Rentizelas (2019) provide a generic indicator system that is independent of industry, Mejias et al. (2019) introduce an approach to evaluate which factors, indicators, contribute to managing a multi-tier sustainable supply chain for a specific industry, fast fashion. These factor indicators, although a prescriptive approach, are used to help describe industrial benchmarking performance. Although the indicator development is the third research question, it is the final and important step to evaluate how well each of the supply chains perform. The approach relies on multiple criteria evaluation techniques, which are also core techniques in the next two articles, following this one, in the special issue. In this paper, the popular analytical hierarchy process (AHP) methodology (Saaty, 1980) is proposed as the MCDM tool to integrate the factors into a single indicator. The information for the evaluation of the three fashion industry organizations is gathered from publicly available sustainability reports and the textile industry's Higg Index. The AHP approach provided an analysis to compare the three organizations. Although limitations exist, the technique provides a starting point for benchmarking companies on sustainability indicators. Further refinement can improve application, although the approach can be applied to multiple industries. The paper also touches on transparency and traceability of information. This issue

is a major concern in monitoring and validating supply chain sustainability across multiple tiers. Although not covered well in this special issue, emergent technologies such as blockchain technology (Saberi et al., 2019) may be integrated with these types of systems for greater information transparency and traceability.

The next study, Tseng et al. (2019), considers how service innovation plays a role in sustainable product-service systems (SPSS). As part of sustainable consumption and production, these SPSS become critical and include consumer, the focal organization, and various suppliers who may offer services in addition to product delivery. The linkage of these services makes managing products even more complex. Innovations not only need to consider products, but also their accompanying services; thus the additional complexity. Given the relative uncertainties and variations, fuzzy systems are used in stages to determine weights and performance. Eventually these are integrated across factors. Even the listing of factors requires development. A comprehensive listing of factors is given and some screening can help reduce these factors to make the technique more manageable. In this case the example of the textile industry is provided, more complex products and supply chains, may encounter greater complexities. But, even in these simpler cases the complexity of such tools remains; as various stakeholder inputs may still be required. This issue is not mentioned as a limitation, but many academic analytical models can fall into practical disfavor without appropriate decision support tools to aid in the process.

Next in sequence is Mohammed et al. (2019), who investigate one of the most prevalent concerns in sustainable supply chain management, the selection of suppliers (Govindan et al., 2015). Supplier selection requires consideration of multiple criteria. The number of criteria expands for sustainable supplier evaluations due to the additional, beyond-business, dimensions considered. The authors extend the supplier selection evaluation to also include order allocation; thus, a supplier has to be selected and assign orders to them. In their model, they not only consider a focal organization's, factory's, market demand, but also how to place orders amongst selected suppliers, making this a three-tier network for selection and assignment. This study contributes to research going beyond the selection decision, which may be considered strategic, with tactical order allocation. For example, some recent works have also sought to not only select suppliers but link them up to supplier development (Trapp

and Sarkis, 2016). Mathematical programming optimization approaches, as stand-alone or integrated decision support models, are popular for these investigations due to the capability of integrating together multiple levels – strategic, tactical, and operational-- of planning and analysis.

This special issue has a variety of methodological and theoretical approaches represented. The next seven articles of this special issue each utilize game theoretic analyses. Each with some variation. These articles alone could represent a special issue on the topic. We will now describe the goal and outcomes of the articles.

Heydari et al., (2019), consider the situation that two types of supply chains, dual reverse supply chains exist for the same product family. In one channel a traditional retailer driven supply chain exists. In the other channel an e-channel, electronic retails sales, drives the supply chain. Experiments using a Stackelberg game theoretic model is used to evaluate the alternative chains; multiple tiers are assumed in the case examples. Open, closed, and transitional triad relationships are examined; with greening cost and green-level elasticities considered as variations in the models. A series corollaries based on the simulated results provide insight into what happens when different supply channel structures are utilized. Some of the results reinforce previous, non-green, supply chain studies, some results counter-intuit.

An important aspect of sustainable supply chains, and by extension multi-tier supply chains, is the reverse logistics channel. Reverse logistics and reverse supply chains are needed to 'close-the-loop'. These are essential concepts and tools towards implementing circular economy business models (De Angelis et al. 2018; Gupta et al. 2018). This special issue includes this paper by Chen et al., (2019) and four other special issue papers that explicitly (one of which was the previous articles by Heydari et al. (2019)) and centrally speak to the closed loop nature of sustainable supply chains. Reverse logistics activities alone may be a multi-tier supply chain. In what has become a standard game theoretic approach of comparing cooperative and non-cooperative game theoretic supply chain situations (e.g. see Bai and Sarkis, 2016), three models are used. These models include Stackelberg and Nash equilibria game theory models, and a cooperative game theoretic model. Cooperative, collaborative efforts, as identified by previous empirical and theoretical studies, some of which have already been described in this special issue, are shown to be preferable in terms of costs and

profits across the supply chain. Promoting environmental awareness also leads to higher overall systemic supply chain profits. In many circumstances it was found that even though individual companies may benefit from uncooperative behaviors, the overall system can lose. The issue evolves on how to share benefits across the supply chain where the overall benefit is realized by all partners. This situation becomes one of the limitations facing these theoretical outcomes.

Comparing competitive or non-competitive environments is one way to apply game theoretic approaches to investigate contextual relationships. Game theory can also be utilized in other ways. An example of utilizing game theory to allocate pollution responsibility across supply chain networks is developed by Ciardiello et al., (2019). In this situation a cooperative game with Shapley values is used to investigate three responsibility allocation principles, local, upstream and downstream responsibility. The model developed utilizes actual information from a building and construction materials setting. Company and LCA data are utilized to develop the necessary data set to evaluate the game theory formulation. They tie the variations in results to implications on possible emphasis and leadership within supply chain decisions. Practically, who controls or manages the supply chain's responsibilities can provide very different results. Although real data is utilized to show the differences, it would be interesting, as alluded to by the authors, on what would happen if true leadership is taken by various partners in a supply chain and how that affects pollution emissions in a multi-tier setting. One aspect that could be more fully developed is who in the multi-tier supply chain has the resources to manage this pollution situation most effectively.

The article by Ciardiello et al., (2019) applies cooperative game theory to a networked supply chain. The next article of the special issue (Yu et al., 2019) utilizes a non-cooperative game theoretic perspective as applied to a supply chain network. Equivalent variational inequality formulations are utilized in their paper. Progressive emission tax policies are utilized to evaluate carbon emissions reductions in a competitive environment. The model is useful for policy makers to determine tax policy, or by industry to evaluate technology, in this case alternative transportation technology, alternatives. In the example simulated runs, emissions tax rates are increased. The resulting findings show that there is sensitivity to these tax rates in terms of decisions to utilize cleaner technologies across the supply chain, but there are

impacts on profit, costs, total emissions, and interestingly, demand. These patterns are clearly identified and intuitively appealing. Implications for specific competing factors and their responses to the policies, as well as customer pressures and concerns, are well described. How each stage in the supply chain reacts, although not evaluated in this study, could have been evaluated showing the power of the model.

Similar to the game theoretic network study of Yu et al., (2019), Chen and Chen (2019), the next paper in the special issue, consider how governmental policy and consumer responses affect supply chain sustainability and profitability. In this case the regulatory policy focuses on product stewardship and producer responsibility; especially pertinent to the waste electrical and electronic equipment (WEEE) regulations (Koh, et al., 2011) and reverse supply chains. Another difference for this paper's supply chain model is an assumption of a hybrid non-cooperative and cooperative game. Regulatory policies may influence one or many stages of the supply chain. Although many regulatory policies are regional or nationally focused, their influence can cover the whole world through supply chains. It is for this reason that many types of regulatory policies, especially ones that closely relate to product stewardship, are inextricably linked to global supply chain sustainability practices. The authors derive seven theorems based on their conceptual models. These theorems are based on supply chain and competitive contexts such as ensured justice, voluntary or group design improvements, and size effects along a market continuum. A description of why the theorems would hold provides practical insights from the theoretical outcomes.

The closed-loop nature multi-tier sustainable supply chains occurs in this next article (Wang et al., 2019) within a remanufacturing setting. Remanufacturing is one of the "re's" of closed loop supply chains and utilizes a product core to rebuild the remainder of the product. Most of the difficulties in remanufacturing is the collection parties and other vendors who may be involved. Another issue that arises is the competition between new products and remanufactured products. This paper looks at the various competitive aspects that occur in a closed loop supply chain. Competition can occur at companies at the same tier, or even across tiers -- for example, an OEM and a remanufacturing organization – and amongst multiple suppliers, whether it is the collector, sorter, and remanufacturer. This paper focuses on product and organization competition. The various scenarios, although theoretical, are

common. The paper results in a number of propositions and three major observations based on a numerical study. The propositions focus on aspects related to decisions by the manufacturer, recycling market characterizations, and issues related to supply chain governance. The observations focus on customer sensitivity to prices and attitudes towards products. This expands the modeling and integration of stakeholders. The issues related to regulatory and environmental policies, as observed in some of the other game theoretic studies, were not as well developed. This study focused most on more traditional pricing and market economics.

A relatively unique application of recycling and hazardous waste are end-of-life drugs and medications. The design and development of networks for collecting unused medicines is introduced as a game theoretic model in the next special issue article by Hua et al., (2019). In this case using consumers as a major source of the material, with retailers and pharmaceutical manufacturers as major organizations involved. Four different models are utilized to investigate the relationships and parametric outcomes. A major focus of this article looks at how to motivate consumers to return their medicine. This article integrates marketing theory in addition to reverse logistics methods for collection purposes. The three contexts were advertising, points-exchange, and joint approaches. Similar to other studies with variations in cooperative and non-cooperative games (Chen et al., 2019 in this special issue, for example), the greater the cooperation among supply chain partners, the greater the profitability. As can be seen by the series of articles that utilize game theoretic approaches, various mechanisms and managerial decisions related to how to motivate returns, who collects returns, and pricing come into play. First-party (manufacturer), second-party (retailer), third-party (reverse logistics provider), and consumer interplay in these contexts play a large role. In these cases each paper provides a variation on how to model and the competitive environment. Some of the studies explicitly include environmental sustainability concerns; others are implicit because the products and materials collected are meant to address a ‘re’ activity. Overall, the results show that if there is a large return rate by customers, at least initially, advertising is the best approach. Lower return rates usually point to a points exchange strategy. These results may be intuitive based on costs. Advertising costs may be very large, but can be dissipated across greater volumes. It is more cost effective to

motivate smaller groups with points as an incentive; if the return groups become too large, then points can become costly.

Overall, what these seven game theoretic articles show is the flexibility of game theoretic modeling to investigate these, and potentially many other, sustainable multi-tier supply chain concerns.

The next series of articles to appear in this special issue apply mathematical linear and non-linear programming and optimization. In each case there is an explicit consideration of environmental sustainability parameters or decision variables.

The paper by Darvish, et al., (2019), seeks to evaluate and investigate how integrated traditional logistics optimization problems solve joint environmental and cost factors. These traditional production- and inventory-routing models do not typically incorporate emissions. In this case production, transportation, and retailing tiers of the supply chain are considered. There is a long history of multi-echelon inventory control optimization models appearing even before the term supply chain management came into wide use (Minner, 2003). There are many such opportunities to further traditional optimization across multiple tiers of the supply chain using additional sustainability elements, such as, in this case, emissions. In this case additional complexities are added, and solution techniques to take advantage of the model structure can help to improve solutions for these increasingly complex formulations due to the additional sustainability criteria to be evaluated.

Food supply chains are probably the most interlinked between social and environmental sustainability concerns. The United Nations sustainable development goals (SDGs) (Griggs et al., 2013), explicitly have seventeen goals and many focus on hunger and poverty. Making sure that food security exists and that it exists in an environmentally sustainable way is a difficult balance to manage. In this case there may be co-benefits of food security and lessened use of natural resources and emissions, but there can also be tradeoffs. These tradeoffs can also occur with economic measures. The focus of the next special issue article by Maiyar and Thakkar (2019), considers the most effective intermodal transportation design along a multi-layered network. Consolidation, location, and hub design characterizations are evaluated. Given the heuristic and complex nature of the solutions, Pareto optimal diagrams

were used to examine the tradeoffs between social, environmental and economic costs. Even with the various complexities the authors arrive at a very succinct conclusion: for this situation, for minimizing sustainability costs, hub location, moderate consolidation costs, and high vehicle resource availability are important. These latter dimensions are described and detailed in the article.

The penultimate article in this special issue (Taleizadeh and Moshtagh, 2019) also considers the closed-loop nature of multi-tier supply chains. Recycling is central to the optimization modeling effort focusing on a consignment, vendor managed, inventory scheme. Collectors, as in many of the reverse logistics and supply chain models, play a critical role; in addition to the standard forward supply chain tiers exhibited by manufacturers and retailers. Strategic operational decisions such as level of integration, cost and selling price of manufacturing and remanufacturing products, and quality acceptance characterizations are evaluated using numerical examples. Each dimension causes a shift in decisions and preferences. These shifts are described in series of graphics and descriptions. There are also interactions amongst some of these study dimensions such as the quality of returns is influenced by pricing and incentives. These incentives and pricing are critical to establish and balance a returns market and can become a complex and is a relatively poorly understood concept. This paper adds to the body of knowledge on these managerial concerns.

The final article in this special issue, (Song et al., 2019) is only a final article because of its unique methodology. This paper takes a policy analysis level perspective to consider pollution emissions along land supply chains. In this case, instead of considering organizational supply chains as the level of analysis, natural resource and trade level, analysis was utilized. This unique perspective can influence other supply chain analysis levels. Also, many of the papers considered policy and had policy implications, this paper considers a region and its supply of natural resources. The evaluation affects many industries in a region in China. The interactions of technological, environmental, energy and economic systems are evaluated. The system dynamics model became quite complex, but more realistic. An interesting methodological contribution was taking the system dynamics information with a further evaluation, not detailed, using data envelopment analysis (DEA).

Summary and Conclusion

This special issue is positioned to catalyze a very complex and difficult research stream. The research stream is also critical to our long term social and environmental survival. Although the mathematics, research questions, and outcomes may serve an academic contribution, we were also looking to practical impact and influences. The insights provided by this work are broad, whether it is individual manager or organization level insight or insights at supply chain and policy levels, the contributions are extensive.

We have also learned in this process. As editors we saw those papers that did not appear in this special issue as well as papers that did appear. There was much knowledge imparted and we are better for it. We hope that the articles here provide substantial sowing of the seeds to generate important and significant research on multi-tier sustainable supply chains for years to come.

Researchers from across disciplines, not only operations research and economics, but policy, engineering, sociology, and even the humanities and arts should join together to address some of this world's wicked problems. Progress needs to be taken, a web of knowledge and creativity is needed to help supply the safety net for our society. We still have a chance to make this world a better place for future generations. We must not lose this motivation and focus. This special issue is only a microcosm of the much greater effort we need to transform our world to be sustainable.

As guest editors we wish to thank the contributors, those that were published and those that submitted. Without them, we would not have this knowledge to disseminate. We thank the dozens of reviewers. Without their volunteer efforts, we would not have the quality of papers and studies we now have. Also a thank you to the editors of the *International Journal of Production Economics* to understand the importance of this and related topics. It is part of the growing history of the journal to support research in the area of "Compassionate Operations" (Sarkis, 2012) and supply chain resource sustainability (Koh et al, 2017).

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Article Title	Authors	Sustainability Issue	Research Methodology	Empirics and Data	Tiers
Unlocking effective multi-tier supply chain management for sustainability through quantitative modelling: lessons learned and discoveries to be made	Charbel Jabbour, Ana Beatriz de Sousa Jabbour, Joseph Sarkis	General Sustainability	Literature Review	Publication Content Analysis	Multiple Industrial
Extending the reach of multi-tier sustainable supply chain management - insights from mineral supply chains	Philipp C. Sauer, Stefan Seuring,	Minerals - Natural Resources	Delphi Study	Expert Opinion - Statistical	Up to Nine
Sustainable multi-tier supply chain management: The role of supply chain leadership	Fu Jia, Yu Gong, Steve Brown	Recycling, Food, Natural Resources	Case study - Primary	Qualitative-Coding	Three +
Assessment sharing intra-industry strategic alliances: Effects on sustainable supplier management within multi-tier supply chains	Sabrina Lechler, Angelo Canzaniello, Evi Hartmann	General Sustainability	Case Studies - Primary	Qualitative - Coding	Three+
Third party social sustainability assessment: Is it a multi-tier supply chain solution?	Claire Hannibal, Katri Kauppi	Social Sustainability	Case Studies - Primary	Qualitative-Coding	Three + up to 7 Tiers
The Role of Suppliers in Promoting Environmental Sustainability	Mengfeng Gong, Yuan Gao, Lenny Koh, Charles Sutcliffe, John Cullen	Environmental Sustainability	Multiple Regression	Secondary Archival Data	Three
The Effects of Supply Chain Collaboration on Performance and Transaction Cost Advantage: the Moderation and Nonlinear Effects of Governance	Ki-Hyun Um, Sang-Man Kim	Social Relationships	Econometrics - Hierarchical Regression	Web Based Survey	Two
The Role of Supply Chain Orientation in Achieving Supply Chain Sustainability	Akshay Jadhav, Stuart Orr, Mohsin Malik	General Sustainability	Structural Equation Modeling	Survey Questionnaire	Two +
An innovative eco-intensity based method for assessing extended supply chain environmental sustainability	Andrea Tuni, Athanasios Rentizelas	Carbon Emissions and Water	Eco-Indicators	Secondary Archival Data	Three
Traceability management systems, capacity building and joint long-term planning as new tools for improving sustainability in the fast fashion multi-tier supply chain	Ana María Mejías, Roberto Bellas, Juan E Pardo, Enrique Paz	General Sustainability	Multiple Criteria Indicator	Secondary Archival Data	Three +
Service innovation in sustainable product service systems: improving performance under linguistic preferences	Ming-Lang Tseng, Kuo Jui Wu, Anthony Chiu, Ming Lim, Kimhua Tan	Recycling - Solid Waste	Fuzzy multiple criteria	Industry Data Collection	Multiple Industrial
A hybrid MCDM-FMOO approach for sustainable supplier selection and order allocation	Ahmed Mohammed, Irina Harris, Kannan Govindan	Carbon, Environmental, and Social	Fuzzy multiple criteria	Case Study - Primary	Three
Pricing and greening decisions in a three-tier dual-channel supply chain	Jafar Heydari, Kannan Govindan, Amin Aslani	Greening Costs	Game Theory	Simulation	Three
Reverse Logistics Pricing Strategy for Green Supply Chain: a View of Customers' Environmental Awareness	Daqiang Chen, Mehmet Demirbag, Joshua Ignatius, Marianna Marra, Danzhi Sun, Shalei Zhan, Chenyu Zhou	Recycling - Solid Waste	Game Theory	Simulation	Three
Pollution responsibility allocation in supply networks: A game-theoretic approach and a case study	Francesco Ciardiello, Andrea Genovese, Andrew Simpson	Pollution emissions	Game Theory	Case Study - Primary	Four-Network
The sustainable supply chain network competition with environmental tax policies	Min Yu, Jose Manuel Cruz, Dong Michelle Li	Pollution emissions	Game Theory	Simulation	Five - Network
Fair sharing and eco-efficiency in green responsibility and green marketing policy	Yenming J Chen, Tsung-Hui Chen	Recycling - Solid Waste	Game Theory	Conceptual - Axiomatic	Three
Hybrid Closed-loop Supply Chains with Competition in Recycling and Product Markets	Nengmin Wang, Qidong He, Bin Jiang	Recycling - Solid Waste	Game Theory	Simulation	Three
Analysis of Advertising and Points-exchange incentive in a Reverse Supply Chain for Unwanted Medications in Households Based on Game Theory	Meina Hua, Ivan Ka Wai Lai, Huajun Tang	Solid and Hazardous Waste	Game Theory	Simulation	Three
Trade-offs between environmental and economic performance in production and inventory-routing problems	Maryam Darvish, Claudia Archetti, Leandro C Coelho	Carbon Emissions	Linear Mathematical Programming	Simulation	Three
Modelling and analysis of inter-modal food grain transportation under hub disruption towards sustainability	Lohithaksha M Maiyar, Jitesh J Thakkar	Food Security, Emissions	Non-Linear Programming, Particle Swarm Optimization	Primary and Secondary data	Network
A consignment stock scheme for closed loop supply chain with imperfect manufacturing processes, lost sales, and quality dependent return: Multi Levels Structure	Ata Allah Taleizadeh, Sadegh Moshtagh	Recycling - Solid Waste	Non-linear Mathematical Programming	Simulation	Four

Simulation of land green supply chain based on system dynamics and policy optimization	Malin Song, Xin Cui, Shuhong Wang	Multi-media pollution	System Dynamics - DEA	Secondary Archival Data	Multiple Industrial