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Unchaining supply chains: Transformative leaps toward regenerating social–ecological systems

Jury Gualandris[1] | **Oana Branzei**[1] | **Miriam Wilhelm**[2] | **Sergio Lazzarini**[1,3] | **Martina Linnenluecke**[4] | **Ralph Hamann**[5] | **Kevin J. Dooley**[6] | **Michael L. Barnett**[7] | **Chien-Ming Chen**[8]

[1]Ivey Business School, Western University, London, Canada

[2]Vienna University of Economics and Business, Vienna, Austria

[3]Insper Institute of Education and Research, São Paulo, Brazil

[4]Centre for Climate Risk and Resilience, UTS Business School, University of Technology Sydney, Sydney, Australia

[5]UCT Graduate School of Business, University of Cape Town, Cape Town, South Africa

[6]W. P. Carey School of Business, Arizona State University, Tempe, Arizona, USA

[7]Rutgers Business School, Rutgers University, New Brunswick, New Jersey, USA

[8]Nanyang Technological University, Singapore

Correspondence
Jury Gualandris, Ivey Business School, Western University, London, Canada.
Email: jgualandris@ivey.ca

Abstract

The worsening climate, biodiversity, and inequity crises have existential implications. To help resolve these crises, supply chains must move beyond a *minimal harm* approach. Instead, supply chains must make positive contributions to and harmoniously integrate with the living systems around them. Despite agreement on this urgent need, supply chain management research still lacks a shared roadmap for establishing economically sustainable supply chains that actively *regenerate* social–ecological systems. This essay deepens the understanding of regenerative supply chains, inviting supply chain scholars and practitioners to rally around timely questions and codevelop new answers. We first scrutinize the paradigmatic assumptions that continue to anchor contemporary research and practice in supply chain management, showing how these once helpful assumptions now hold the community back from seeking much needed solutions. We then offer real-world examples and synthesize emerging arguments from multiple disciplines to propose three new principles of regenerative organizing: *proportionality*, *reciprocity*, and *poly-rhythmicity*. We also delve into the implications of pursuing these regenerative principles for supply chain coordination, governance, and resilience. Finally, we reflect on the fit of empirical research designs and methods for examining the *creation* of new regenerative supply chains and the *conversion* of existing supply chains.

KEYWORDS
adaptation, climate change, coordination, degeneration, regeneration, research methods, resilience, stakeholder governance, supply chain management

INTRODUCTION

The recent decades have witnessed the alarming deterioration of social–ecological systems as human activities caused climate (e.g., Garner, 2023; Intergovernmental Panel on Climate Change, 2023; Naughten et al., 2023), biodiversity (e.g., Jaureguiberry et al., 2022), and inequity (e.g., Oxfam, 2023; World Inequality Database

[WID], 2022) crises. These interlinked crises have been disrupting global supply chains: Extreme weather events interrupt access to resources on which modern economies have come to depend, and the suffering they cause gives us collective pause to reflect on what the supply chain management discipline has been doing.

Pagell and Shevchenko (2014) called out the state of research on sustainable supply chain management, which is focused on the design, coordination, and governance of supply chains "with the minimum expectation of a truly sustainable supply chain being to maintain economic viability, while doing no harm to social or environmental systems" (p. 45). A major conclusion they drew was that research offered "limited insight into how to create an economically viable supply chain that at a minimum creates no harm and may even have positive or regenerative impacts on social and environmental systems." The need to go beyond a *minimal harm* logic and move toward supply chains that *regenerate* social–ecological systems is more salient than ever, given the accelerating climate, biodiversity, and inequity crises.

A decade after Pagell and Shevchenko's (2014) article, research has examined important themes such as sustainable sourcing (e.g., Wohlgezogen et al., 2021), circular supply chains (e.g., Dhanorkar et al., 2019; Lee & Tongarlak, 2017), and social and environmental upgrading in global supply chains (e.g., Castaldi et al., 2023; Gereffi & Lee, 2016; Krishnan et al., 2023). Yet regenerative supply chains require more, calling managers to recognize, integrate, and purposefully contribute to local communities and natural ecosystems so their organizations can begin to rebuild natural and social capital (Konietzko et al., 2023; Muñoz & Branzei, 2021). While ecologists have studied regenerative systems, their frame is of a local landscape ecology. The unique aspect of a regenerative supply chain is that it connects locales and landscapes that are otherwise disconnected, via the economic and physical transactions involved to create and distribute a product or service. Building regenerative supply chains entails aligning organizational knowledge, decision-making, and activities by diverse supply chain members with the structures and dynamics of social–ecological systems in diverse geographies (including "Global North" and "Global South" contexts), at multiple levels (local and global), and across time horizons (short term and long term) (e.g., Bansal et al., 2018; Slawinski et al., 2021).

Unfortunately, we still know little about the design, coordination, and governance of regenerative supply chains. This essay aims to invite and motivate knowledge-building about ways of organizing that help social–ecological systems to thrive and that promote equitable, not only efficient, economic exchanges. To underscore the value of regenerative thinking and doing, we first briefly expose the largely unquestioned assumptions underpinning modern supply chains by showing how they cause the degeneration of natural and social capital. Then, we propose an initial definition of regenerative supply chains and flesh out three core principles of regenerative organizing, namely, *proportionality*, *reciprocity*, and *poly-rhythmicity*. Future research should critically examine, validate, and expand these principles. We also delve into the implications of regenerative efforts for supply chain coordination, governance, and resilience. The essay closes with reflections on the fit of empirical research designs and methods for examining the purposeful *creation* of new regenerative supply chains and the *conversion* of existing ones.

QUESTIONING SUPPLY CHAIN MANAGEMENT'S PARADIGMATIC ASSUMPTIONS

Research in supply chain management has been mainly concerned with maximizing economic and operational outcomes like profitability, efficiency, responsiveness at mix and volume, and conformance and performance quality (e.g., Fisher, 1997; Lee, 2002). The discipline has successfully investigated ways to reduce variability, shorten cycle times, and minimize bullwhip effects (Lee et al., 1997), and these discoveries remain useful today. Yet these aspired performance improvements commonly neglect social and ecological outcomes. Scholars and practitioners often study, engineer, and manage supply chains as if these complex inter-organizational systems would operate in a vacuum, in the absence of surrounding social–ecological systems that both contribute to and are impacted by their activities.

Even in research and practice focused on sustainability and sustainable supply chain management, the common frame is about how to increase profits and operational performance while minimizing harm (Gao & Bansal, 2013; Montabon et al., 2016; Pagell & Shevchenko, 2014). This orientation toward minimizing harm and doing so only as a secondary priority to securing strong economic outcomes is rooted in paradigmatic assumptions, listed below, that permeate Western society and paradigmatic assumptions to which some cultures, for example, indigenous cultures, did not and still do not subscribe (Cruze & Baker, 2023; Meadows, 1999, 2001):

1. A supply chain should support a focal company's primary responsibility to maximize profit (e.g., Friedman, 1951). To maximize profit, a focal company and its supply chain need to seek growth and economies of scale, using natural and social

capital as instrumental inputs of production (e.g., Ricardo, 1780; Smith, 1776).
2. To maximize profits, a focal company needs to control its supply chain and drive improvement through top–down mechanisms (e.g., Gereffi, 1994; Porter, 1989).
3. To maximize profits, a focal company and its supply chain need to quickly adjust sourcing, production, and distribution cycles to always satisfy final demand at the least cost (e.g., Fisher, 1997).

According to systems theorists (e.g., Hutchins, 2012; Kania et al., 2018; Meadows, 1999), these paradigmatic assumptions profoundly shape the way supply chains are designed, coordinated, and governed. Supply chains managed according to these assumptions deteriorate natural capital, compromising natural cycles[1] and other ecosystem services that are essential for human survival (e.g., Tubiello et al., 2022). These supply chains also create injustices by exposing workers to health and safety hazards (e.g., Chamanara et al., 2021; Cousins et al., 2020; Jacobs & Singhal, 2017) and disrupting indigenous socio-cultural relationships with land and sacred entities (e.g., Urzedo et al., 2022). Social–ecological systems are harmed when supply chains push profit, efficiency, and responsiveness to the extreme and when powerful focal companies demand that supply chain members lower prices and lead times, all while externalizing social and ecological costs (Caro et al., 2021; Glover & Touboulic, 2020).

We first delve into the adverse ecological consequences associated with the pursuit of ever-higher efficiency (i.e., Assumption 1 above). According to the theory of comparative advantage (Ricardo, 1780), wealth is maximized when companies specialize and scale their operations to leverage higher productivity for specific goods in specific localities. However, local ecosystems can be severely damaged when production processes are scaled beyond what would be ecologically sustainable in the localities where companies operate (Lee & van Sice, 2011; Meadows & Randers, 2004). Moreover, when efficiency leads to significantly lower prices, Jevon's paradox notes that resulting growth in resource consumption can overcompensate for efficiency gains, leading to greater total exploitation of social–ecological systems (Alcott, 2005; Hegwood et al., 2023). Finally, beyond scale, efficiency objectives commonly give rise to specialization, as in the case of monocropping in agriculture, which has negative consequences for biodiversity (Jaureguiberry et al., 2022). To function capably, ecological systems rely on diverse living species and human and non-human activities interacting in specific proportions (Richardson et al., 2023).

Pursuing efficiency without deliberate limits also triggers unintended consequences for social systems. While the pursuit of efficiency may temporarily boost overall wealth, this wealth tends to concentrate, creating a lasting advantage for few dominant players (Martin, 2019). Such market concentration ultimately leads to market failures and social injustices in the short term while constraining upward social mobility in the long term (Oxfam, 2023; WID, 2022).

To illustrate the consequences of pushing efficiency beyond the breaking point of social–ecological systems, let us examine the agri-food sector. Land is often conceptualized as a scarce resource, necessitating efficient use through intensified cultivation and global trade. In Indonesia, this belief has led to dedicating over 55% of arable land to palm oil production, justified by claims that palm plants offer the most efficient yield of vegetable oil per hectare of land (World Wildlife Fund [WWF], 2023). This unbridled search for efficiency has contributed significantly to deforestation, particularly of diverse, old forests, and the conversion of carbon-rich peatlands, diminishing the Earth's carbon sequestration capacity and emitting substantial amounts of greenhouse gases (Xu et al., 2022). Additionally, concerns persist regarding modern slavery within the palm oil industry. Similar destructive patterns have been observed in other countries, such as the United States (Martin, 2019), Canada (Canadian Climate Institute [CCI], 2022; WWF, 2020), and the United Kingdom (Galbright, 2023), and other sectors, such as manufacturing (Foer, 2023).

Now, let us consider two other paradigmatic assumptions that profoundly affect supply chain management: Performance improvements should be driven top–down by large focal companies (i.e., Assumption 2 above) and targeted to responsively match final demand at the least cost (i.e., Assumption 3). These assumptions empower large focal companies, foster hyper-competition within and across their supply chains, and reduce supply chain members' agency in improving their operational, social, and ecological performance (Glover & Touboulic, 2020). Growing evidence indicates that top–down, buyer-driven

[1]The European Union defines natural cycles, such as carbon cycle, nitrogen cycle, and water cycle, as natural processes in which elements are continuously cycled in various forms between different compartments of a natural environment (e.g., air, water, soil, and organisms). These cycles represent an important type of ecosystem services, called *supporting services* (i.e., those maintaining a viable diversity of species for a functioning habitat). Other ecosystem services, generating direct and indirect contributions to humans' well-being, are *provisioning services* (i.e., those producing food, water, wood, oil, and medicine), *regulating services* (i.e., those sequestering carbon to regulate climate, flood regulation, pollination, and water purification), and *cultural services* (i.e., those recreating and emotionally and physically recovering through the interaction with nature) (e.g., Costanza et al., 1997).

governance, facilitated through global sustainability standards and auditing systems, has produced limited improvements for social–ecological systems (e.g., Conniff, 2018; Moog et al., 2015). This inability to produce a positive impact becomes particularly evident when focal companies insist on both low prices and high responsiveness to demand (Caro et al., 2021; Wohlgezogen et al., 2021), as well as when sustainability standards and auditing systems lack customization to suit the unique structures and dynamics of specific localities (Holzberg, 2023; Simpson et al., 2021).

Do supply chain members possess the will and the ability to steward their local ecosystems and communities? One excellent example of regenerative efforts at the grassroots level is the recent initiative taken by different industry associations in the garment sector in Tirupur, India (Apparel Resources, 2017). The Noyyal River had become so heavily polluted by textile dyeing that the water was no longer fit for agricultural uses. The Tirupur Exporters' Association, Dyers Association of Tirupur, and Knit Cloth Manufacturers Association collaborated on cleaning up the most heavily polluted 9-km stretch of the Noyyal River, contributing their equipment and workforce to the cause. This example challenges the assumption that improvement can only be driven top–down by large focal companies.

In conclusion, as they pursue efficiency and responsiveness without recognizing and respecting surrounding social–ecological systems, focal companies and their supply chain members may take actions that unravel the natural proportions, relationships, and rhythms that sustain life on Earth. The question is not whether these companies can improve performance at the expense of surrounding living systems but rather how companies may lead the way to realign the dynamics of economic and living systems so they can ensure mutual gains. While supply chains may have grown disconnected from the very fabric of social–ecological systems they are part of, the continuance of their operations now depends on restoring alignment.

EXPLORING NEW ORGANIZING PRINCIPLES FOR REGENERATIVE SUPPLY CHAINS

Rooting for ever-higher efficiencies and responsiveness through top–down governance is not working. What is the alternative? This section outlines differences between supply chains that work to *minimize harm* (as discussed above) and supply chains that are *regenerative*, defined as inter-organizational networks that sense and embrace surrounding living systems, aligning their decision-making and actions to these systems' structures and dynamics, in a way that allows for such systems to gain strength, build resilience, and sustain life (Muñoz & Branzei, 2021, p. 510). Regenerative supply chains are designed and managed to purposefully enhance, and benefit from, the health of social–ecological systems (Hahn & Tampe, 2021; Konietzko et al., 2023; Slawinski et al., 2021). A supply chain is not regenerative if it attends to nature but harms society or vice versa (Buckton et al., 2023). It is also not regenerative if only one process or locale is regenerative; being regenerative is a supply chain-wide trait.

As companies are increasingly called on to recognize and report their contributions to nature and society, some are beginning to recognize and shift away from harm-inducing assumptions and instead prioritize positive impact (e.g., Diebel et al., forthcoming). Table 1 proposes a few examples of focal companies engaging in practices that hold promise for regenerating social–ecological systems. Future studies should take a closer look at these cases before declaring them as "regenerative" (Jain & Gualandris, 2023; Nemes et al., 2022); yet an initial examination of these examples suggests three new principles of regenerative organizing, summarized in Table 2: *proportionality*, *reciprocity*, and *poly-rhythmicity*. As companies move past harm-inducing paradigmatic assumptions, they should deliberately embrace these principles in advance of implementation, when *creating* new regenerative supply chains, or when *converting* existing supply chains into regenerative ones.

Proportionality

Building upon the cases summarized above (Table 1) and recent biodiversity literature (e.g., Flinn et al., 2008; Mathews, 2016), the principle of *proportionality* points to the necessity for focal companies and their supply chains to restore a suitable variety of native species in specific localities and to adjust the scale and scope of production and consumption within the proportions that social–ecological systems can tolerate best. Proportionality aligns the patterns and extent of growth of diverse species and human and non-human activities in mutually respectful and reinforcing ways.

Examples like Inversa (Table 1) foreground the possibility and desirability of avoiding excessive specialization and scaling to maintain a suitable proportion of natural, societal, and economic activities in specific areas. This company tailored its sourcing activities to stop the proliferation of invasive species in specific ecosystems. Inversa works with individual divers to hunt invasive lionfish in the Gulf of Mexico, dragonfin in the Mississippi River,

TABLE 1 Examples of emerging regenerative supply chains.

	Case summary
Creating new regenerative supply chains	**Inversa**—The company uses its fashion supply chain to regenerate oceans by removing invasive species. As a result of human error in the late 1980s, a handful of lionfish slipped undetected into Atlantic waters off the coast of Florida. In less than 40 years, the invasive lionfish has destroyed native fish populations and coral reefs from Brazil to Boston. By fishing lionfish in specific areas, Inversa's supply chain protects up to 70,000 native reef fish that invasive lionfish eat in their lifetime and 42+ million livelihoods in the Western Atlantic Basin that make their living from coral reefs. To accomplish this positive impact, Inversa created a new leather category from invasive species. Its "invasive" leathers each addresses a unique environmental crisis. Invasive lionfish leather helps to restore coral reef ecosystems in the Gulf of Mexico, invasive dragonfin leather helps to rehabilitate the Mississippi River, and invasive python leather helps to revive the Everglades, a UNESCO World Heritage Site (Inversa, 2023). **Jarki Sarki**—The company emerged as a response to the over-exploitation of predator species, namely, salmon and perch, resulting in a consequential proliferation of prey species such as roach and vendace in Finnish inland lakes. Recognizing the ecological imbalance, the company strategically created a new supply chain to valorize the surplus prey species. Now marketed through platforms across Nordic countries, each jar of organic seasoned fish sold contributes to purifying drinking water for over 1 million people. Restoring native biodiversity in upstream lakes helps reduce eutrophication and purify the water feeding downstream basins. Jarki Sarki tailored the scope and scale of its supply chain activities to valorize a fish species that was out of proportion economically; it leveraged the triadic reciprocity between customers requiring nutritious products, local lakes requiring help to regain biodiversity, and local communities needing clean water; and it aligned production and distribution activities with diverse natural rhythms (e.g., predator–prey temporal dynamics and harvesting of local seasonings and spices on their respective growth cycles) (Albareda & Branzei, 2023). **Calmura Natural Walls**—As a start-up founded in 2016 in British Columbia, Canada, this company recovers wasted resources such as eggshells, mollusk shells, and wood ash to produce natural construction materials made of cob, adobe, lime, and pozzolans. The company enormously benefits from a deep understanding of natural cycles. For example, eggshells, which contain calcium carbonate ($CaCO_3$), are transformed into quicklime (calcium oxide [CaO]) through a high-temperature process called "calcination." Quicklime is then turned into lime (calcium hydroxide [$Ca(OH)_2$]) by adding water through a natural process known as "curing." When lime is used in construction and exposed to air, lime gradually reacts with and absorbs carbon dioxide (CO_2) from the atmosphere, becoming harder and more durable over time. This process is referred to as "carbonation." By leveraging such natural cycles, Calmura Natural Walls avoids the environmental costs associated with limestone mining and the disposal of organic materials like eggshells. Additionally, their innovative materials are expected to have a longer lifespan than traditional options, and when these materials reach the end of their useful life, they can be repurposed as soil amendments to support the growth of new biomaterials (Calmura, 2023).
Converting traditional supply chains into regenerative ones	**Natura & Co**—The largest cosmetics and beauty company in Brazil, Natura has developed a community-based program to help their growers of natural ingredients to restore and conserve the Amazon rainforest. A few decades after its creation, Natura's leadership began to view the company as part of a larger system that required social–ecological balance to prosper. According to their 2009 annual integrated report, the company and its supply chain were re-imagined as living organisms in a dynamic set of relationships. Hence, suppliers of natural ingredients were asked to work together to assess better the social and ecological implications of growing and harvesting processes and co-create holistic ways to regenerate the Amazon and sustain its local communities (Boehe et al., 2014; Keating, 2021). **Interface**—According to the United Nations Environment Programme (UNEP), abandoned, lost, or discarded fishing gear makes up about 10% of marine waste. Interface has

(Continues)

TABLE 1 (Continued)

	Case summary
	developed a supply chain that tackles this growing environmental problem by recycling fishing nets into carpets while empowering some of the most disadvantaged communities in the Philippines. Since 2012, Interface has collected 66,860 kg of nets from residents in 14 collection sites in Danajon Bank and the Bantayan Islands. Moreover, inspired by natural carbon cycles, Interface has recently launched new "carbon negative" carpet tiles that store carbon during production by using recycled content and bio-based materials (Interface, 2023).
	Hewlett–Packard (HP)—In collaboration with local informal waste pickers in Haiti and a plastic recycler, HP has been experimenting with circular processes to collect and recycle ocean-bound plastics to reduce carbon emissions and protect natural ecosystems. Their effort has required innovative plastic compounds, product designs, and reverse logistic processes, all developed in partnership with retailers, waste pickers, recyclers, and parts suppliers worldwide (Gualandris & Lee, 2021). HP is further investing in end-of-life plastics' collection, sorting, and recycling to achieve 75% circularity in products and packaging by 2030, hoping to strengthen the health of social–ecological systems by closing the loop on harmful materials and providing local communities with decent and stable sources of income.

Abbreviation: UNESCO, United Nations Educational, Scientific and Cultural Organization.

TABLE 2 Traditional paradigmatic assumptions versus emergent regenerative principles.

	Proportionality	Reciprocity	Poly-rhythmicity
Traditional paradigmatic assumptions	Contemporary supply chains are designed and managed to gain efficiency through scale and specialization, with little consideration for social–ecological systems balance (Assumption 1).	Supply chains are designed and managed top–down by powerful actors, with little consideration for the quality of mutual relationships with other supply chain members, local communities, and ecosystems (Assumption 2).	Supply chains are designed and managed for high responsiveness to final demand, with little consideration for social–ecological systems' rhythms and dynamic patterns (Assumption 3).
Emergent regenerative principles	Supply chain members identify and restore a suitable, *balanced variety* of native organisms and species and adjust the scale and scope of production and consumption within the proportions that social–ecological systems can best tolerate.	Supply chain members appreciate and co-manage the *mutual impact* of their activities on social–ecological systems and vice versa across diverse geographies (including "Global North" and "Global South" contexts), at multiple levels (local and global), and across time horizons (short term and long term).	Supply chain members consider the multiplicity of *simultaneous rhythms* characterizing social–ecological systems and make strategic, tactical, and operational decisions that align with such rhythmic patterns.

and pythons in the Everglades to create fashionable leather products. Moreover, the company works closely with local communities to consume or sell the fillets, stimulating local micro-economies. Finally, Inversa works closely with conservation organizations to ensure that leather production facilities operate at a scale that does not interfere with local ecosystems by, for example, over-consuming freshwater.

Similarly, Albareda and Branzei (2023) document how, when predator species like salmon and perch were fished to extinction in Finnish inland lakes, and prey species such as roach and vendace proliferated, the company Jarki Sarki (Table 1) started to target such prey species and valorize them commercially by creating from scratch local, then regional, then national supply chains. Jarki Sarki recognized that predator and prey fish species in the Finnish lakes were out of balance and actively worked to reinstate a well-functioning food web by adjusting the scale (volume of fish caught) and scope (variety of fish caught) of their operations to contribute to local social–ecological systems. With

each product sold, the proportions of predator and prey species are continuously kept in check, helping to maintain the quality of habitat for various organisms, including those that contribute to ecosystem services like nutrient cycling and water purification (e.g., preventing algae overgrowth and overgrazing of proper vegetation).

The proportionality principle calls attention to counter-balancing actions that repristinate natural proportions and to operational and organizational arrangements that balance human and non-human activities. In regenerative supply chains, human actors are called on to reduce harm already done and harmoniously integrate with nature and society, whether by taking out pollution of one invasive species or roach at a time, as did Inversa and Jarki Sarki, or by taking back toxic materials, as did Hewlett–Packard (HP) and Interface (Table 1).

Reciprocity

Regenerative supply chains operate in *reciprocity* with social–ecological systems when interactions between supply chain members, local communities, and broader nature are designed to benefit multiple human and non-human actors in a community of life (Buckton et al., 2023). A historical reference is the design of the city of Jamshedpur, India, by the founder of Tata Group. The city's urban design deliberately factored in what we refer to today as biophilia—spaces and encounters between human and non-human actors that restore and retain mutually beneficial relationships.

From an ecological standpoint, the cases summarized in Table 1 suggest that products and processes can be inspired by nature to become more eco-effective rather than merely eco-efficient. Eco-effectiveness is concerned with how any material or energy dissipated by any one operational process or organization can feed productively into another process or organization (Niero et al., 2017). Designing for eco-effectiveness requires assessing reciprocity between seemingly unrelated operational processes and organizations in ways that benefit nature while also creating economic value by leveraging scope economies (Gómez & Lee, 2023). For example, Calmura Natural Walls recovers discarded materials, including eggshells, mollusk shells, and wood ash, to fabricate sustainable construction materials such as cob, adobe, lime, and pozzolans. The innovative compositions of these materials confer extended durability compared to conventional alternatives. Notably, upon concluding their operational lifespan, these materials can be repurposed as soil amendments, contributing to the cultivation of novel biomaterials (Calmura, 2023).

The principle of reciprocity reorients managerial attention to recognize and reorganize waste as a resource, designing supply chain activities that collect and channel this resource responsibly, contributing to the regenerative capacity of social–ecological systems. Consequently, instead of following a demand-driven approach to business, familiar to many modern supply chains (i.e., "We want to produce *X* to satisfy customer *Y*. What do we need to do to produce *X* as efficiently as possible?"), the principle of reciprocity encourages supply chain members to embrace a supply-driven approach to business (i.e., "We have these resources. What can we make of them that is valuable to both society and nature?") (Dhanorkar et al., 2019; Lee & van Sice, 2011; Sarasvathy, 2001).

By re-orienting attention, the principle of reciprocity reconnects humans not only with nature but also with each other. Instead of focusing on the quantity of transactions, regenerative supply chains value the quality of relationships. "In our pursuit of efficiency, we have come to believe that routine labor is an expense to be minimized. Companies underinvest in training and skill development, use temporary and part-time workers, … and design jobs to require few skills so that they can be exceedingly low paid." (Martin, 2019). As the famous case of Mercadona reminds us (Ton & Harrow, 2010), labor is not just a cost but is a valuable resource, a customer, a citizen, and a steward; high labor budgets can improve mental health and drive good operational execution and higher local sales (O'Boyle et al., 2016; Ton, 2012).

Numerous biological systems, such as forests, exhibit a distinctive organization grounded in altruistic and cooperative behaviors (e.g., Simard et al., 1997). Social systems also flourish on the fundamental principles of reciprocity, encompassing both direct forms, exemplified by a relational exchange (where one individual reciprocates a favor after receiving one), and indirect forms, wherein one's benevolence toward others is driven by the expectation that such altruism will be reciprocated by someone else later (Bosse et al., 2009; Gualandris et al., 2021; Nowak & Sigmund, 2005).

Reciprocity was implied by Wu and Pagell's (2011) observation of "equal footing," whereby some companies deliberately provide decent-paying jobs and stability to their employees, suppliers, and communities, while respecting nature's structure and dynamics. Making reciprocity explicit draws attention to how supply chain activities impact social–ecological systems and vice versa, as demanded by the emergent "double materiality" principle in corporate reporting (Adams et al., 2021, p. 5).

Poly-rhythmicity

Besides proportionality and reciprocity, regenerative supply chains must also juggle many rhythms simultaneously,

a property we refer to as *poly-rhythmicity*. Social–ecological systems orchestrate multiple, simultaneous natural rhythms that can positively influence or impinge on one another. Managers are skilled jugglers of multiple rhythms, too, but the complexity and mutual interference of living systems quickly overwhelm the tools and frameworks commonly used to elevate economic efficiencies and responsiveness to final demand.

To illustrate the principle of poly-rhythmicity, let us consider forests. Several natural forces—including fires, droughts, and insect cycles—maintain the balance between forest and prairie grassland by allowing various species to thrive and sustain life. If the rhythms of such natural forces are intentionally or unintentionally altered due to human activity, nature and its ability to sustain life will deteriorate. For example, due to climate change, fires and droughts are becoming more frequent, overwhelming the ability of Canadian boreal forests to regenerate (Whitman et al., 2019). Generally, wildfire and other disturbances kill old trees, enabling a new generation of trees to sprout from the seeds of old trees. However, if another wildfire or drought occurs in the exact location within a short interval, the disturbance kills the new generation before new trees are matured enough to produce seeds, thereby undermining the forest's ability to sustain life. Disturbances, including supply chain activity, intersect with local ecosystems' dynamic rhythms.

In agriculture, for example, following the principle of poly-rhythmicity avoids intensification practices that constrain livestock movement to accelerate the meat production cycle, with strong unintended consequences for social–ecological systems (e.g., EFSA Panel on Animal Health and Welfare, 2012). The poly-rhythmicity principle generalizes to social systems, too; for example, managerial beliefs shaped around the importance of efficiency can inadvertently lead companies to invest too little time in relationship building and maintenance with local communities, eroding the resilience these relationships could afford (Cruze & Baker, 2023; Hamann et al., 2022), especially during difficult times like the COVID-19 pandemic. The poly-rhythmicity principle requires supply chain members to consider the simultaneous rhythms characterizing social–ecological systems and to make strategic, tactical, and operational decisions that align with such rhythmic patterns.

While distinct, the principles of proportionality, reciprocity, and poly-rhythmicity are mutually reinforcing. Regenerative companies practice all three, as exemplified by the example of Jarki Sarki in Table 1. Helping social–ecological systems to gain strength (purposeful regeneration) requires achieving a balanced variety of diverse species and human and non-human activities in particular areas (proportionality), which requires organizations to comprehend the impacts of these species and activities on one another (reciprocity). This understanding, in turn, may prompt managers to broaden their comprehension of simultaneous natural rhythms (poly-rhythmicity), setting up supply chain activities that operate in unison with social–ecological systems.

Coordination, governance, and resilience of regenerative supply chains

The proposed regenerative principles have a lot to offer to supply chain managers. Yet their implementation complicates the coordination and governance of supply chains, as well as potentially hampers their resilience. In the following, we elaborate on the challenges and opportunities for supply chain management research and practice.

First, as supply chain members embrace regeneration, *operational coordination* will become more complex and ambiguous. To illustrate, consider the case of McCain Foods. As this large buyer enrolls large and small potato farmers worldwide in its regenerative program (McCain Foods, 2022), the complexity of handling and scaling food production and distribution increases relative to the old, traditional monocropping approach. Potatoes will be produced together with crops of different species in specific proportions to provide a range of growth cycles (annual, bi-annual, and perennial), ward off pests, and fix nutrients in the soil. Complexity increases with the introduction of livestock such as poultry and cattle, again in specific proportions relative to the available land and its ability to absorb nutrients and reproduce crops and grass in specific time frames. Not only is production becoming more complex, but operational coordination across supply chain tiers must also adapt to handle a more extensive mix of co-products. Demand for potatoes can no longer be used as the primary signal to coordinate specialized supply chain activities because of production interdependencies with other crops, chicken, and beef (Gómez & Lee, 2023), unless the demand for potatoes is prioritized over that of other co-products, which are then processed and distributed following a push model.

Research could investigate how, to achieve effective regeneration, supply chain members coordinate the production and distribution of multiple co-products. As traditional supply chains are retrofitted to become regenerative, how does the structure of existing supply chains retard the development of regenerative processes? How does introducing regenerative principles and processes in some supply chain components (e.g., sustainable

forest management, regenerative farming, and food discard upcycling) affect processes and structures in other parts of the supply chain (e.g., coordination across diverse market channels and distribution networks)? As new regenerative supply chains are created, what capabilities and technologies help companies sense potential operational constraints and opportunities from surrounding social–ecological systems? And how do supply chain members coordinate their activities to balance efficiency and responsiveness at a macro, supply chain level with regenerative outcomes at local, community, and ecosystem levels? Examining diverse operational coordination mechanisms in regenerative supply chains represents a clear avenue for future research.

Second, besides operational coordination, once supply chains reorient toward regeneration by embracing one or more of the three principles defined above, traditional *governance models* bear scrutiny. Even though top–down, buyer-driven governance increases decision-making expediency and reduces transaction costs, it may be incapable of helping supply chain members manage the mutual impact of their activities on each other and social–ecological systems (Bridoux & Stoelhorst, 2022; Gualandris et al., 2015). Who makes strategic and tactical decisions in regenerative supply chains, and through what deliberation processes?

Natura & Co is an example of a company that transitioned from top–down governance toward an increasingly inclusive, shared governance model to support its regenerative production processes (Boehe et al., 2014). The company developed a complex web of relationships in the Amazon rainforest to procure "biodiversity inputs"—nuts, fruits, and natural ingredients used in its cosmetics products. Typical suppliers are small family farmers in forest areas, often organized as cooperatives or local associations. McGahan and Pongeluppe (2023) found that forest conservation is around 19% higher in the areas where Natura & Co is present. The company achieved this outcome by paying farmers higher prices for their biodiversity inputs and by fostering vertical and horizontal interactions between farming cooperatives, local communities, public actors, and even competitors to collectively manage local value-creating resources—a system that Gatignon and Capron (2023) and Patala et al. (2022) interpret as a polycentric governance arrangement.

This polycentric governance model is characterized by mutual adjustment between supply chain members and external stakeholders, practices for collective agency, and structures for sharing valuable public and private resources. It extends traditional relational governance models usually adopted in global supply chains when product specifications are difficult to codify, transactions are complex, and suppliers' capabilities are rare and valuable (Gereffi et al., 2005).

The example of Natura & Co triggers several reflections. How should interactions between supply chain members and their surrounding social–ecological systems be structured, especially in contexts historically characterized by the exchange of private goods through market-based transactions? Why would leading focal companies like Natura & Co listen to broad societal demands, invest in regenerative efforts, and support the creation of polycentric governance models, especially when such actions do not generate clear economic returns in the short term (e.g., Crane et al., 2014; Pagell et al., 2020)? How can focal companies work with supply chain members and other stakeholders to challenge widespread paradigmatic assumptions of efficiency and responsiveness and to embrace new regenerative principles of collective organizing? How can supply chain members self-organize to discuss and deliberate on key strategic decisions concerning the scale and scope of their regenerative efforts? And how do cultural values, mutual norms, and codes of conduct evolve as supply chain members address their collective dilemmas? The examination of alternative governance models (Gatignon & Capron, 2023; Patala et al., 2022) and the moral determinants (Lazzarini et al., 2020; Taylor & Rosca, 2023) of regenerative efforts represent an important avenue for future research.

Third, what are the implications of embracing regeneration for the *resilience* of supply chains and that of surrounding social–ecological systems? The concept of social–ecological systems emphasizes the dynamic interplay between social and ecological components of an integrated community of life, where changes in one system can profoundly affect the other (Buckton et al., 2023). Social–ecological resilience, consequently, refers to the ability of linked social and ecological systems to navigate non-linear and transformative changes that can emerge from disruptions (e.g., Folke et al., 2010). Social–ecological resilience operates within a multi-level framework, capturing the dynamic interactions between social and ecological elements, including supply chains, across multiple levels of analysis (Novak et al., 2021). Understanding the complex feedback loops inherent in social–ecological resilience is also likely to be a foundational element in designing resilient supply chains that promote the well-being of interconnected living systems (Wieland & Durach, 2021).

We must recognize that pursuing regenerative principles binds supply chain members deeply within complex social–ecological systems, potentially leading to lock-ins and exposure to systemic vulnerabilities (e.g., Kennedy & Linnenluecke, 2022). For example, if

companies producing construction materials were to embrace the model proposed by Calmura Natural Walls, improving circularity and reducing their dependence on virgin natural resources, the sector would collectively move closer to regenerative rates. However, simply lowering resource extraction and dependence is not automatically building social–ecological resilience. Rural communities that are heavily dependent on mining limestones and other natural resources for livelihoods would need to transition to alternative sources of income, which requires significant time and investments (knowledge, skills, education, planning, community engagement, etc.), calling for short-term public policies to mitigate impact. Lowering resource extraction and dependence does not automatically improve resilience at the company or supply chain level. Supply chain members would have to carefully consider their production processes and inter-organizational structures to manage diverse sources of variability and avoid being locked into fragile ways of operating.

Regenerating complex social–ecological systems demands a more nuanced, gradual, agile approach to managing supply chains. Building or retrofitting supply chains that contribute positively to social–ecological resilience without becoming too vulnerable necessitates a holistic understanding of reciprocal impacts at multiple levels of analysis (e.g., with ecosystems and with various stakeholders along the supply chain and within local communities). Can supply chain members regenerate social–ecological systems without de-stabilizing their operational and economic performance? Integrating resilience thinking and multi-level perspectives into the formulation of regenerative processes, such as is done in jurisdictional approaches (Kittinger et al., 2021), holds the promise of fostering more harmonious relationships between supply chains and surrounding social–ecological systems.

Future studies could examine how embracing the principle of proportionality helps supply chain members identify, prevent, and respond to critical shocks that can disrupt the dynamic balance of diverse species and human and non-human activities in specific localities. Similarly, research could investigate how supply chain members can collaborate to identify mutual relationships with social–ecological systems, injecting agility and adaptability into specific processes and inter-organizational structures. Finally, we could investigate how supply chain members that closely monitor and adjust their operations to multiple rhythms can positively impact local communities and ecosystems while also stabilizing their economic performance. As we move forward in the study of regenerative supply chains, key questions will concern the critical scrutiny of regenerative principles, processes, and structures that support all forms of life.

HOW TO STUDY REGENERATIVE SUPPLY CHAINS

In the prior section, we conceptualized three new principles of regenerative organizing and explored their implications for supply chain management. This final section addresses three methodological implications arising from these distinctive principles.

First, the novelty introduced by regenerative organizing has implications for the methodological alignment between research questions, data sources, and analytical approaches. Edmondson and McManus (2007) argue that nascent research fields are likely to focus on relatively more open-ended research questions; use qualitative data from interviews and observations; and emphasize inductive, theory-generating analytical processes. As the field matures, the research questions may explore relationships between established and new constructs, and both qualitative and quantitative data may be analyzed to develop new propositions and perhaps test new hypotheses.

If well-established methods are adapted to examine regenerative supply chains, this adaptation process will need to consider *what* is studied and *how* this is done. For example, surveys and experiments may be adapted to assess principles like reciprocity or poly-rhythmicity, but this will be no mean feat, given the likely absence of validated constructs for such principles and corresponding practices. This is another reason why much of our initial research on regenerative supply chains will likely be inductive and qualitative to clarify and elaborate core constructs. Thus, we may expect that research probing some of the more novel dimensions of regenerative supply chains will likely emphasize inductive designs with qualitative data, whereas those studies connecting or comparing aspects of regenerative organizing to established constructs in the supply chain literature may prefer a hybrid approach. For example, abductive approaches to identify and explore anomalies between theoretically informed expectations and empirical observations, including a possible focus on extreme cases (Sætre & Van de Ven, 2021), could be used to better delineate regenerative efforts from more traditional efforts that minimize harm.

A second, related methodological implication arises from the observation that research on regenerative supply chains has a foundational practical and moral orientation, as outlined when discussing key implications for coordination, governance, and resilience. It challenges

some of the root assumptions of much prior research and practice in supply chain management, including an overriding emphasis on economic efficiency, top–down governance, and responsiveness to final demand. Such a paradigmatic shift also means that much of our research attention may need to go to unusual and uncommon organizing efforts (e.g., Natura & Co and Jarki Sarki), given that regenerative innovation may be driven more by practitioners than by researchers (Hamann et al., 2020; Konietzko et al., 2023), which further underscores the merits of adopting the abductive approach mentioned above, optimal for studying outliers and poorly understood phenomena.

By the same token, researchers may want to take on the challenge to not merely follow, describe, and explain innovative practice, but to be more ambitious in supporting proactive change toward regenerative supply chains. This could take the form of action research, where researchers work together with practitioners to develop innovative practices, strategies, and interaction patterns. For example, Drimie et al. (2018) report on an action research project to facilitate greater inclusion of small-scale farmers in South African food supply chains, emphasizing the importance of involving commonly excluded groups in the action research process itself. It can also entail designs in which the researcher undertakes "explicit efforts to improve organizations" (Dunbar & Starbuck, 2006, p. 171). Ideally, such efforts include randomization of treatments and inclusion of control groups, though such rigor of design is sometimes infeasible in field settings. In such cases, statistical methods are available to offset these limitations (Duflo et al., 2007; Duflo & Kremer, 2005).

More ambitious research approaches may also seek to shape future business practice through prospective and performative theorizing. Such "theory building would seek to unleash the performative potential of imagination—the production of theories that may become real because people act on them and thereby shape social reality, rather than represent or predict it" (Gümüsay & Reinecke, 2022, p. 240). This may involve diminishing the bounds of our "disciplined imagination" (Weick, 1989). For example, researchers in interdisciplinary environmental studies have explored exciting ways to work with musicians or visual artists to both generate and communicate visions of the future that create possible avenues for transformative action (Pereira et al., 2018).

This observation brings us to the third methodological implication. The sections above have highlighted how regenerative supply chains will need to be designed and managed with much closer awareness of and sensitivity to the social–ecological systems in which they are embedded and to which they either erode or positively contribute. As researchers analyzing or prospectively reimagining supply chains, we will thus need to become more conversant in the theories, constructs, and methods used by other scientists studying social–ecological systems (e.g., Biggs et al., 2021). This will likely involve expanding our own theoretical and methodological repertoires and increasing collaboration with researchers in the natural (e.g., ecology and biology) and social sciences (e.g., sociology and psychology).

CONCLUSION

Research and practice still have a long way to go to advance the understanding and dissemination of regenerative supply chains. So where can we go from here? We foresee two paths for future research: *creation* and *conversion* (Table 1). Creation celebrates the emergence of born-regenerative supply chains, as products, production processes, and supply chain structures are being deliberately designed to reverse harm, giving priority to nature and communities, and pacing goals and growth to mother nature (e.g., Calmura Natural Walls, Inversa, and Jarki Sarki). Differently, conversion invites the transformation of existing supply chains into regenerative ones, drawing attention to the dynamic proportions, relationships, and rhythms characterizing social–ecological systems (e.g., HP, Interface, McCain Foods, and Natura & Co). The future of our economies, and perhaps existence, will play out in between these two extremes.

As new supply chains are born as alternatives that oppose exploitative ways of linking supply with demand, they may create friction and frustration with existing arrangements. Whether or not one prevails remains to be seen. Emergent supply chains can lose their regenerative properties if efficiency-led growth keeps disconnecting them from the principles of proportionality, reciprocity, and poly-rhythmicity necessary to regeneration. Traditional supply chains can experiment with regenerative properties as they begin to respond to shocks that disrupt or compromise supply or are called to internalize their unintended consequences. As policy makers and consumers ask for greater transparency and compare the harms and benefits accruing to different supply chains, emergent organizing principles, coordinative processes, and governance structures such as those being documented here may become the new normal. Supply chain management researchers are in the complicated but enviable position to trace this momentous and consequential change, map the terrain, and offer tools that shape our shared future.

ORCID

Jury Gualandris https://orcid.org/0000-0003-4866-7050
Oana Branzei https://orcid.org/0000-0002-4477-0192
Miriam Wilhelm https://orcid.org/0000-0001-5782-4674
Sergio Lazzarini https://orcid.org/0000-0001-8191-1241
Martina Linnenluecke https://orcid.org/0000-0001-7984-9717
Ralph Hamann https://orcid.org/0000-0002-4694-1987
Kevin J. Dooley https://orcid.org/0000-0001-9993-5161
Michael L. Barnett https://orcid.org/0000-0003-0279-0766
Chien-Ming Chen https://orcid.org/0000-0002-1745-2527

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