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Research Article

Technological game changers: convergence, hype, and evolving supply chain design

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Abstract

Paper aims: Poor supply chain design cost Boeing, Chipotle, Lego, and Toyota billions in revenues, capitalization, and reputational value. This paper introduces a purposive, systematic supply chain design process, identifies economic disrupters, and describes how a proactive approach to supply chain design can support and propel visionary business models.

Originality: The paper introduces punctuated equilibrium as a critical lens to evaluate how technological disrupters will transform supply chain design and the development of Industry X.0.

Converging game changers will place more companies at existential risk, making it essential to identify potential trigger events and how they might change the competitive rules.

Research method: Conceptual development following over 100 interviews with companies during a 10 year longitudinal study.

Main findings: Emerging technologies promise/threaten to transform the economy on the scale of the industrial and information revolutions. We discuss how each technology might influence supply chain design. Individually, each technology represents a game changer. Their convergence requires purposive supply chain design to shape the emergence of Industry X.0.

Implications for theory and practice: Managers who employ astute scanning and nuanced scenario analysis will position their companies to not only identify inflection points but also accurately assess the timing of the transformation. This skill set will be critical to designing and developing a supply chain able to support and propel visionary business models.

Keywords

Evolution theory. Punctuated equilibrium. Technology disruptors. Purposive supply chain design.

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1. Introduction

Over 20 years ago, Boston Consulting Group's Harold Sirkin noted, "As the economy changes, as competition becomes more global, it's no longer company vs. company but supply chain vs. supply chain" (Elliff, 1996, p. 55). Two years later, Massachusetts Institute of Technology's Charles Fine called supply chain design the company's "ultimate core capability" (Fine, 1998). Strategic decision makers had recognized that the resources and capabilities needed to develop a distinctive competitive advantage often reside outside their company's boundaries (Dyer & Singh, 1998). Two core organizational routines enable supply chain design's influence and impact: 1) the ability to identify vital complementary competencies and 2) the ability to gain access to these capabilities through effective inter-organizational governance (Eisenhardt & Martin, 2000; Fawcett & Magnan, 2001). Supply chain design and its core value-added routines had become a sought-after "enabler of winning business models" (Lyons, 2003).

Yet, within a few years, pundits began to recognize the challenges inherent to building a supply chain-enabled business model. Specifically, although modern information technologies had enabled supply chain integration (Fawcett et al., 2008), actually building a collaborative supply chain was harder than analysts had envisioned. Beth et al. (2003, p. 64) noted, "Despite years of technological and process advancements, an agile, adaptive supply chain remains an elusive goal". More pointed in their criticism, Sabbath & Fontanella (2002) pronounced collaborative supply chain design as "[...] the most popular—and the most disappointing—strategy that has come along to date". Despite the competitive benefits exemplified by relational exemplars like Honda and Toyota, most firms struggled to leverage supply chain resources and relationships to achieve distinctive advantage (Daugherty et al., 2006; Nyaga et al., 2010; Jin et al., 2013). Supply chain design as the "enabler of winning business" models had succumbed to the hype cycle, passing through the peak of inflated expectations and landing in the trough of disillusionment (see Figure 1).

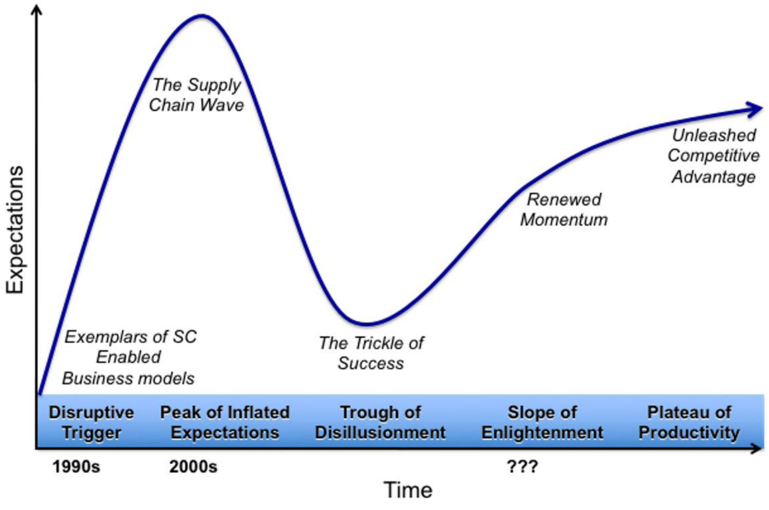

Figure 1. Supply chain design and the hype cycle.

Today, despite well-documented challenges, companies continue to rely on emerging technologies to enable unique supply-chain leveraged business models. And, sadly, they still struggle to leverage supply chain design for competitive success. Consider two examples.

1. **Amazon's Pricey Fulfillment.** Amazon.com has built an extensive network of over 328 fulfillment centers to be able to offer Prime members free two-day delivery (MWPVL International, 2018). The result: Over 100 million consumers pay $119 per year to participate in the Prime program, spending almost twice as much on Amazon as non-Prime members ($1,300 versus $700) (Weise, 2018). Although Prime has helped Amazon capture about 44% of U.S. e-commerce sales, Amazon's last-mile delivery costs have kept it from ever making a meaningful profit in its core business;
2. **Tesla's Production Hell.** Tesla sells elegant cars that employ the most advanced propulsion and autonomous-driving technologies. The result: Tesla's market capitalization reached $51 billion in 2017, surpassing General Motors as the most valuable automaker in the U.S. (Grant, 2017). Yet, Elon Musk has acknowledged that Tesla is stuck in "production hell," unable to produce and deliver cars to customers who paid $1,000 deposits to pre-order the Model 3. By early 2018, Tesla was burning through cash, causing investors to worry about Tesla's long-term solvency—and to realize that competitive success depends as much on supply chain design as it does on product design and technology development.

For both Amazon and Tesla to fulfill their promise as innovative champions, they need to evolve their supply chains to be able to profitably deliver on their wildly popular value propositions. Importantly, this challenge does not belong solely to disrupters like Amazon and Tesla, but extends to almost every company. Ultimately, in a market besieged—and enabled—by emerging technologies, better understanding how the new technologies will influence supply chain design is relevant and timely.

2. The evolution of supply chain design

For most of the 20th century, the efficiency goals expounded by the theory of the firm (Coase, 1937) and transaction-cost economics (Williamson, 1979) motivated the design and management of supply chain relationships. These transaction-oriented theories identify the firm as the entity of competition. The goal was to minimize costs and risks. Companies did this by pitting suppliers against each other via competitive bidding in order to obtain the lowest costs (Dyer & Singh, 1998). Buyer/supplier relationships tended to be contractual, short-term, loosely coupled, and often adversarial (Williamson, 1981).

In the 1980s, Toyota changed the way companies view supply chain design. Indeed, the market success of Japanese manufacturers—e.g., Honda, Kawasaki, Sharp, and Toyota—led analysts to reevaluate competitive practices (Schonberger, 1982; Hayes & Wheelwright, 1984). The pundits realized that longer-term, more tightly coupled buyer/supplier relationships promoted by Just-in-Time sourcing and the Japanese Keiretsu structure were enablers of lean's success (Schonberger, 1986; Womack et al., 1990). One result: The term supply chain management was coined in 1982 to recognize that these close, collaborative buyer/supplier relationships could be a major determinant of competitive success (Womack et al., 1990; Birou & Fawcett, 1993).

By the end of the 20th century, theorists had articulated that firms can use close supply chain relationships to gain access to complementary resources and achieve relational rents (Dyer & Singh, 1998; Gulati & Singh, 1998). Yet, few firms have fully grasped how to design supply chains to maximize the gains available through relational strategies (Villena et al., 2011; Terjesen et al., 2012; Jin et al., 2013). Supply chain design has emerged as a critical, but difficult competency to master (Fawcett et al., 2015, 2016).

2.1. Consequences of poor supply chain design

Despite the widespread recognition that supply chain design is a competitive determinant, companies have continued to struggle to design and build supply chains capable of enabling winning corporate strategies. Equally important, as the following real-life cases exemplify, poorly designed supply chains damage corporate reputations and profitability.

1. **Lego's Outsourcing Conundrum.** Responding to a change in consumer tastes that favored technology-enabled toys, which caused a DKK 1.8 billion loss in 2004, Lego decided to outsource and offshore production. Lego outsourced production to Flextronics, a well-respected contract manufacturer, only to discover that its new supply chain could not support operations and sales. Lego discovered that production of plastic blocks was a hard-to-replicate competency. As performance declined, threatening to push Lego into bankruptcy, senior leadership canceled the outsourcing agreement, bringing production in house;
2. **Boeing's Global Partnership Model.** To reduce up-front development costs for the 787 (aka, the Dreamliner)—from an estimated $10 billion to as little as $4 billion—Boeing outsourced design and production of major components to supply partners in Asia and Europe. Partners would deliver components to Boeing's Everett facility for final assembly. Unexpectedly, when the time came to assemble the first plane, the parts didn't fit. Fixing the supply chain delayed the 787's launch by over three years. Final development and launch costs soared to over $30 billion;
3. **Toyota's Overextended Network.** At the turn of the century, Toyota's leadership set a new goal: Become the world's largest automaker by 2010. Toyota ramped up production around the world and began to rely on computer design tools to shorten product development times. By 2008, Toyota's manufacturing footprint and computer-enabled design had outgrown its human capital. Toyota's famed quality production processes began to break down, tarnishing Toyota's brand and leading to a $1.2 billion fine levied by the U.S. Department of Justice;
4. **Chipotle's Underdeveloped Supply Base.** Chipotle Mexican Grill earned widespread acclaim and exceptional stock-price appreciation for its food-with-integrity business model. However, in the spring of 2015, the supply chain could no longer support the growth. A pork supplier violated animal welfare standards, forcing Chipotle to pull carnitas from menus at 600 restaurants (Ferdman, 2015). Then, 500 Chipotle patrons in 13 states suffered E-coli, norovirus, and salmonella-caused food poisonings. Chipotle's reputation was tarnished, customers lost confidence, and same-store sales dropped, pummeling the stock price by 35% (Gasparro, 2016).

The anecdotal evidence argues that companies that are either unwilling or unable to meticulously and purposively design their supply chains to enable winning business models and mitigate market disruptions are destined for mediocrity—or worse. Yet, as illustrated above, purposive supply chain design is a complex and demanding task. Managers must be able to sense competitive rules—and when or how to change them. They must also learn how to assemble needed competencies. Competencies can be developed internally or acquired through supply chain relationships. However, competencies must align and mesh to create distinctive value. Ultimately, purposive supply chain design is really about building a supply chain team—both composition and chemistry are needed to build a supply chain champion (Fawcett et al., 2017).

2.2. Evolution theory: gradualism or punctuated equilibrium?

Embedded in the discussion of organizational design and transformation is the notion of evolutionary capability; that is, how adeptly and agilely an entity evolves. Evolution enhances a firm's survival prospects only if the speed of the firm's response is proportionate with the temporal requirements of the external environment (Hannan & Freeman, 1984). Two primary evolutionary forms have been described: gradualism and punctuated equilibrium.

Historically, and under normal conditions, competitive rules evolve gradually (Darwin, 1859). At the industry level, incremental improvement—typically focused on cost and quality gains—can keep a company relevant when gradualist evolution prevails. At times, however, the environment shifts toward punctuated equilibrium. Triggering events—like the emergence of a new technology—dictate dramatic adaptation, placing slow-to-change organizations at risk (Eldredge & Gould, 1972). To avoid extinction in a punctuated-equilibrium environment, relentless scanning must be coupled with quick response and radical innovation capabilities (Hannan & Freeman, 1984). In other words, companies must develop first-mover capabilities.

However, from an economic perspective, only rarely do triggering events occur that radically change how businesses and supply chains operate. These triggering events tend to be technology based. For example, the introduction of the steam engine coupled with parts standardization ushered in the industrial revolution. More recently, computers and the Internet have launched the information revolution—and the re-organization of economic activity. Yet, companies are struggling to leverage digitization for profitable competitive advantage. For instance, despite its market dominance (over 44% market penetration), Amazon still does not earn reliable profits on its core business of online retailing. W. Brian Arthur (2003, p. 126) warned that radical "[...] economic transformation is slow not because it requires new equipment but because it requires new—and often not obvious—ways to organize business".

Ultimately, evolution theory yields key insight into the hype cycle (see Figure 2). Specifically, technological disrupters are viewed as triggering events. Analysts tend to believe that change will be rapid and transformative—that is, they see the world as a punctuated-equilibrium environment. The recognition that the rules may be changing—and the fear of fighting tomorrow's competitive battles with yesterday's technology—drives technology adoption (and feeds the hype). Yet, economic transformation is difficult and slow. More challenging, many efforts to evolve capabilities and supply chain design lead to failure. Economic results and risk reset expectations. Radical transformation settles into a gradualist evolution, often marked by trial and error. Over time, companies either abandon the "disruptive" technology or iteratively figure out how to re-organize resources to create unique competencies and achieve economic advantage.

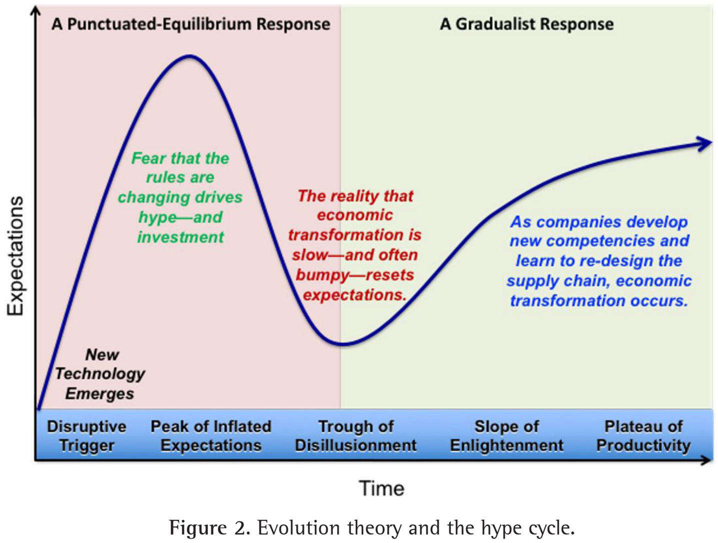

Figure 2. Evolution theory and the hype cycle.

For example, the Internet enabled e-commerce, but it did not solve the problems associated with omni-channel logistics, especially the cost of last-mile delivery (Ellram et al., 2017). In fact, in 2015, Amazon lost $5 billion on last-mile deliveries (Statista, 2016). As a result, after 20 years of evolution, e-commerce still represents only about 10% of total retail sales in the U.S., a little more in Europe, and a lot less in most emerging markets (China is the exception). But, e-commerce is growing and both retailers and their suppliers continue to adapt their supply chain designs.

Ultimately, evolution theory argues that decision makers need to inculcate two capabilities within their organizations:

1. **Scanning.** The ability to assess how, and how fast, a new technology will transform the competitive rules is a required antecedent capability;
2. **Adaptation.** The ability to re-organize resources to build the right new capabilities is a valuable dynamic capability (Eisenhardt & Martin, 2000; Barreto, 2010).

To begin to explore how supply chain design will evolve, decision makers need to identify and evaluate the game-changing role of emerging disruptive technologies.

3. 21st-century supply chain design: converging game changers

The question emerges, "What are the technological disrupters on today's horizon that will change the rules of the competitive game?" Scanning is needed to identify pivotal technologies and consider how their emergence might change the way companies structure and govern winning supply chains (Fawcett & Waller, 2014).

3.1. Additive manufacturing

Additive manufacturing (i.e., 3D printing) offers radical possibilities to postponement, customization in manufacturing, and even prolonging products' useful life. By considering the three dimensions of complexity, customization, and production volume (Conner et al., 2014), additive manufacturing can be applied for companies to fabricate those products with high levels of complexity and/or customization. Conventional manufacturing, which relies heavily on volume production to derive economies of scale, cedes advantage to additive manufacturing when unique needs arise. For instance, Frazier (2014) identified a specific set of applications ranging from biomedical (e.g., dental crowns) to unique aircraft components. We detail four specific supply chain implications of 3D printing.

1. **New Product Development (NPD).** Additive manufacturing is most influential in the NPD process, speeding the development and testing of prototypes. At Ford, 3-D printing has reduced prototyping cycles from three months to as little as a week (Shinal, 2013). Rapid prototyping shortens lead times, allowing multiple iterations in the development process, yielding more innovative and higher-quality products;
2. **Spare parts.** Additive manufacturing's cost/availability equation will transform spares fulfillment models. That is, for most companies, spare-parts management is a costly, but requisite aspect of doing business. By building a world-class spare parts supply chain, Caterpillar offers unmatched service for its equipment wherever it is used—including some of the most remote and hostile environments on earth—helping mitigate a key customer pain point. Although additive manufacturing could dramatically reduce the costs of supporting equipment, it could also render Caterpillar's distinctive service capability obsolete;
3. **Invention.** For the inventor who cannot afford 3-D equipment, third-party design shops (Fowler, 2013) and logistics service providers like UPS (Diakov, 2013; UPS Store, 2017) are investing in 3-D printing as part of their drive to enable a maker movement. One day, the additive-manufacturing-enabled "maker revolution" may affect the economy as substantively as the industrial and information revolutions (Anderson, 2012). Waller & Fawcett (2014) note that additive manufacturing will make it easier for inventors to become entrepreneurs;
4. **Shopping Behavior.** Amazon, always looking for a way to deliver product faster and more profitably to its customers, has applied for a 3-D printing patent. The proposed innovation: Install 3-D printers in delivery vans so Amazon can receive and print customers' orders en route to customers' homes or offices (Bensinger, 2015). As the costs of 3-D printers come down, the homemaker or handyman who needs a single item (e.g., a fitting for the vacuum or a gasket for lawnmower), will soon be able to obviate "not-so-quick-nor convenient" trips to the store. To keep customers coming to stores, retailers will need to place more emphasis on the education and entertainment aspects of shopping (Byron, 2017; Binkley, 2017).

Today, 3-D printing is tweaking supply chain design. Along with increased adoption of micro segmentation of customers in marketing (e.g., Kumar et al., 2016), additive manufacturing will unlock the supply chain's potential to provide increasingly customized solutions unique to individual customer needs as firms identify them through data analytics. The supply chain design objective, then, is for companies to recruit partners that can overcome additive manufacturing's technical limitations on product range and ultimately match the low costs of mass production.

3.2. Artificial intelligence

Artificial intelligence (AI) promises to advance automation to the point where machines are no longer bound by preset algorithms programmed by software engineers. Instead, they will become self-learning entities that constantly monitor, add, and discard conditions salient to accomplishing a particular goal by mapping "percepts to actions" (Russell & Norvig, 1995). In its nascent forms, AI is already pervasive. From Google's search algorithms to computerized personal assistants (e.g., Apple's Siri). AI not only serves as a valuable interface to increase consumer embeddedness in a software ecosystem but also as an information channel used by companies to micro-segment markets. AI also employs user-generated data to glean deep insight as to what factors exogenous to a user's actions are primary decision influencers to make products more relevant to individual consumers (Kumar et al., 2016). For members of a supply chain, using AI often involves an evolutionary process whereby current manufacturing and service operations capabilities advance to make the customer's experience easier and better (Silver et al., 2016). Two roles ae emerging.

1. **Optimize Tradeoffs.** Supply chain managers process vast amounts of data to arrive at an optimal decision that balances many conflicting objectives—e.g., cost, quality, and on-time delivery. AI processes in seconds cognitive tasks that would take a human many labor hours, allowing managers to explore issues ranging from gauging demand to modeling commodities prices. For instance, AI could advise managers of optimal production schedules and logistical network configurations to assure supply continuity. Alternatively, AI could assist managers with commodities price hedging to prevent unexpected cost increases;
2. **Mitigating Supply Chain Disruptions.** IBM launched its Watson Supply Chain Solutions with the goal of enhancing supply chain visibility to empower firms to uncover hidden risks that threaten to disrupt operations. The twin disasters of 2011—i.e., the Tohoku earthquake and the Thailand floods—completely paralyzed many firms' supply networks, making a critical point clear: human scanning and planning capabilities are insufficient to mitigate risks (e.g., Lohr, 2011). For some companies, each minute a line is shut down costs $10,000—or more. As operations remain offline, losses increase and customers turn to other suppliers. Not only does AI offer the ability to model potential disruption scenarios and associated continuity plans but AI may also be able to monitor environmental conditions, alerting managers to conditions that portend a disaster. AI may be able to predict the unpredictable.

Ultimately, AI's superior ability to process basic cognitive tasks, such as parsing through millions of data points constantly and to ascribe meaning promises to uncover hidden insights that would likely be missed by managers. Application of AI should, however, be further researched and examined. For instance, AI's focus on data-driven objectivity cannot incorporate innately human parameters such as relationships. Alternatively, AI that is not adequately trained to balance the needs of an entire supply chain could default to the same suboptimal behaviors as a functional silo. Understanding AI's limits is critical to deploying AI-enabled supply chains.

3.3. Autonomous vehicles

On October 20th, 2017, Uber's Otto autonomous tractor-trailer hauled 51,744 cans of Budweiser beer 120 miles across Colorado, navigating the dense traffic of downtown Denver (Rosenbaum, 2016). The successful delivery represents the culmination of extensive research aimed at increasing road safety and reducing capital intensity of transportation models (Fagnant & Kockelman, 2015). Along with freight transportation, passenger transportation also stands to substantially gain from autonomous driving (Fagnant & Kockelman, 2015). One of the greatest benefits promised by automation is the idea that self-driving cars will increase traffic flow predictability by removing human error to increase overall traffic throughput, particularly when vehicles become connected (Talebpour & Mahmassani, 2016). Automated vehicles are changing business models. For instance, General Motors is deemphasizing the manufacture and sale of vehicles to develop a new mobility business (i.e., transportation as service). In freight transportation, capacity will increase as the persistent driver shortage is mitigated (Fagnant & Kockelman, 2015; Talebpour & Mahmassani, 2016). Two core benefits appear to be emerging.

1. **Cost Reduction.** Fully autonomous vehicles are programmed to always obey traffic laws and safety guidelines, promising to reduce the frequency and cost of accidents. Safety is a big selling point. Also important, driverless trucks would eliminate driver shortages (up to 15%) and the disruption of driver turnover (up to 100% per year)—two of the most pressing challenges in the trucking industry. By replacing drivers, autonomous vehicles offer cost benefits via reduced accidents and safety violations as well as lower labor costs (i.e., wages, benefits, and driver recruitment) (Berman, 2013). As these cost advantages accrue, service goals such as 30-minute delivery times may become cost effective;
2. **Service Enhancement.** When a customer places an order, the sooner the product arrives at the customer's doorstep, the greater the sense of gratification. Jeff Bezos formulated Amazon's strategy based on Amazon's ability to shift customer expectations. Thus, Amazon is constantly investing in new delivery models, including the use of drones and autonomous delivery vehicles. As the autonomous vehicle ecosystem matures, Amazon may be able to profitably deliver customer orders in as little as 30 minutes, eliminating the need for customers visit a brick-and-mortar retailer.

To leverage first-mover advantage, companies are reconfiguring their supply chains by teaming up with partners from historically unrelated industries—e.g., Intel with Mobileye; AMD with Tesla; Qualcomm with Volkswagen. The goal: Accelerate the emergence of a service-driven shared economy that emphasizes dynamic capacity optimization over capital ownership. This shift in focus is enabling technology giants (e.g., Google) to directly compete against auto industry incumbents (e.g., General Motors) as providers of transportation capacity. GM, by contrast, hopes to leverage mobility to increase profit margins from the current 7.5% to 20% (Colias & Higgins, 2017). Several issues, however, are delaying the emergence of an autonomous vehicle ecosystem, including regulation, information security (i.e., hacking), and the technology itself (Bonnefon et al., 2016).

3.4. Big data and predictive analytics

Modern information technology enabled the supply chain revolution (Hammer, 1990; Fawcett et al., 2011). Today, the ability to collect data is ubiquitous (e.g., clicks, barcodes, RFID, sensors, and loyalty cards) and data is inexpensive to store. The result: Big Data is enabling managers to make evidence-based decisions in a way that was previously impossible (Waller & Fawcett, 2013a). Big Data is changing the rules in three key ways.

1. **Customer Profiling.** Companies track customer behavior like never before, building profiles that they use to develop new products, manage product portfolios, redesign product displays, target promotions, and optimize pricing (Kumar et al., 2016). Tesco, an early adopter of customer profiling, began mailing beer coupons to shoppers who bought diapers. Why? Analysis revealed that new fathers who were stuck at home tending the baby drank more beer (Steel & Angwin, 2010).

How will data analytics evolve future decision-making? Consider Amazon's predictive shipping experiment. In 2014, Amazon announced its efforts to obtain a patent for "predictive shipping." Amazon claimed that by mining its databases, it could accurately predict and ship what a customer wants before the customer places the order (Bensinger, 2014). But, by 2018, Amazon had yet to begin predictive shipping. Why not? Is Amazon concerned customers might complain, saying, "That is too intimate"? Or, is Amazon concerned about a spike in returns—or worse, that consumers will game the system to extort discounts on shipped-but-not-yet-ordered items? Understanding consumer shopping patterns is easier than managing consumer relationships;

2. **Finding Hidden Connections.** Predictive analytics provide great insight into correlation, but not causality. That is, they can help decision makers identify and connect previously hidden dots. But, will managers have the emotional fortitude to make and stick to decisions based on the analytics—even if/when they do not fully comprehend why? This is a paradigmatic change:

Society will need to shed some of its obsession for causality in exchange for simple correlations: not knowing why but only what. This overturns centuries of established practices and challenges our most basic understanding of how to make decisions and comprehend reality (Mayer-Schonberger & Cukier, 2013).

The fact that "finding hidden connections" can improve resource allocation, customer satisfaction, and profitability raises the question, "Where is the appropriate balance between seeking analytics-based first-mover advantage and striving for causation-driven understanding?" (Waller & Fawcett, 2013a, b).

3. **Machine Learning.** Increased data collection and analysis capabilities is leading to rapid adoption of machine learning, a general-purpose technology that underlies many potential business applications (Brynjolfsson & Mitchell, 2017). For instance, Microsoft collects about a terabyte of production data every day to establish end-to-end visibility of its value-creation processes with supplier, manufacturer, and customer screens. After almost 18 months of development, the system began issuing alerts to production engineers to bring anomalous events to their attention. The next step is for the machines to mimic the engineers. That is, by comparing the nature of each anomaly and the engineering team's response, the machine begins to learn and suggest solutions to anomalies. Over time, machine learning promises to leverage data so machines can solve the simple problems, enabling engineers to focus on more complex challenges (Knoben, 2017).

Although Big Data and Predictive Analytics can have significant influence on how companies manage processes and serve customers, obstacles remain for true value creation. That is because data and insight do not consider context and scope of a decision's impact. An emerging research stream examines specifically the legal and ethical consequences of when predictive analytics violate legal and ethical considerations (e.g., Cohen et al., 2014). Negative consequences abound, as Target learned when its predictive analytics based on consumer shopping habits unintentionally revealed a teenage girl's pregnancy to her parents, who understandably were enraged (Duhigg, 2012). In short, the question of Big Data and Predictive Analytics extends beyond simply predicting and acting on predictions. Decision makers need to evaluate the scope, appropriateness, and consequences of their "predictive" decisions—both on the focal firm and on its supply chain partners and society as a whole (Mittelstadt et al., 2016).

3.5. Blockchain

In a global economy, vast amounts of physical commodities are transferred across the world, often undergoing value-added transformation before being acquired by the end user. Much of this value-creation process remains invisible to decision makers, introducing risk into every transaction. For instance, a supplier might misrepresent the origin or nature of its products or of its performance capabilities (e.g., Ho et al., 2015). The result: A buyer must rely on faith that the supplier is performing to promise. Blockchain, which is a decentralized and distributed digital ledger used to record transactions across many computers so that records cannot be altered retroactively without the collusion of the network, assures data authenticity. Greater transparency will potentially change the way supply chains are designed and managed. Consider three potential applications.

1. **Supply Chain Visibility and Traceability**. In today's global supply chains, information transference concerning material flow is often delayed, incomplete, or inconsistent. Decision-making blind spots result. Risk assessment is difficult. Transactions are highly vulnerable to fraud. For instance, the United States military estimated that up to 15% of its spare parts for weapons and vehicle maintenance are counterfeit (Wagner, 2015). Blockchain authenticates information concerning point of origin as well as chain of custody, making the information available to everyone involved in the transaction. Each transaction generates a new data point in the ledger, enhancing information timeliness. Visibility enables decision makers to hold their supply chain partners accountable, more effectively evaluate risk, and develop better contingency plans;

2. **Coordination and Collaboration.** Enhanced visibility and traceability promises to enable better coordination and collaboration across the supply chain. For instance, food drugs are often identified based on an antiquated system of batch codes printed on the packaging. If a problem is identified and a recall is announced, prolonged delays or inadequate recall scope result in tainted product being consumed. By adopting blockchain, a supplier can quickly identify on the shared ledger the specific shipments that require quarantine and return. A public ledger shared across the entire supply chain makes it easy to alert every member of the chain to problems surfacing at any point in the chain, resulting in rapid recall, improved food safety, and reduced costs;

3. **Corporate Social Responsibility (CSR).** A series of factory fires and building collapses at Bangladesh textile contractors in 2013 resulted in hundreds of worker deaths. Global apparel retailers quickly disavowed working with these contractors. Yet, photos of product with their labels soon appeared in print in the *Wall Street Journal* and other trade press. The retailers were clueless that their suppliers were subcontracting work to unqualified suppliers. Blockchain could have helped prevent this reputation risk by developing a ledger to register qualified

contractors and continuously capturing information on factory payroll and regulatory compliance. Similar measures can be taken for environmental compliance as well as supplier financial health. Upstream visibility to multiple tiers of suppliers can help managers achieve a strategic mix of environmental, social, and economic goals.

Lisa Su, CEO of Advanced Micro Devices, has noted that blockchain is a "positive foundational technology that could change the way we interact." The key is programing blockchain to record complete and objective information for all economic transactions where value changes hands. This reality is also blockchain's greatest weakness: Faulty programming will result in an incomplete blockchain, providing a biased view. Further, blockchain threatens to expose potential trade secrets that serve as the unique resource generating sustained competitive advantage. For instance, a buyer could gain upstream supplier information eventually leapfrogging the supplier to contract directly with the supplier's sources. Absent high levels of trust, suppliers are unlikely to embrace blockchain, greatly limiting its potential applications. Therefore, a broad range of opportunities for research exist on these issues.

3.6. Internet of things

For almost three decades, people have been connecting their computers to the Internet. The advent of the smartphone meant that individuals could connect to the Internet from almost any place at any time. Today, it's not just people but also things that connect to the Internet. For instance, the Nest thermostat enables home owners to control their homes' temperature remotely as long as they have access to the Internet. Similarly, the Ring doorbell send users brief videos whenever someone approaches their front door. The reality is that almost anything can now be connected to the Internet. That's the idea behind the Internet of Things (IoT), which is the "[...] network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment" (Gartner Group, 2018).

According to Gartner Group, the real value of the IoT is to improve control over and visibility or operations, linking supply chain information with key customers, carriers, suppliers, and internal functions. Via IoT, a manager can monitor a production line, remotely diagnosing and fixing problems when they arise. Another application of IoT is asset tracking, which lets decision makers identify the location of a physical asset, divert an in-transit shipment, or, in the future, start making an item (using additive manufacturing) on a truck that is headed to a customer's operation! The possibilities are endless. Although the potential of IoT is considerable, security is a huge issue. In Mid-October 2016, tens of millions of IoT devices globally were hacked and hijacked, shutting the Internet down in many places worldwide. How did this happen? Answer: People left their IoT-enabled security cameras, routers, and smart TVs—with the original passwords, like 1234 (Simon & Selyukh, 2016). Decision makers discovered that it is impossible to do business in an IoT-enabled world when the Internet is down.

3.7. Materials science

Not all technology breakthroughs that will affect supply chain design are driven by data. Modern materials science is changing manufacturing practice. General Motors, for instance, is planning to build its next generation Silverado trucks using carbon fiber—a material that is lighter and stronger than either steel or aluminum. However, carbon fiber is also more expensive and much harder to work with. But, carbon fiber's benefits would help GM improve fuel efficiency and keep highly profitable trucks relevant in a changing regulatory world (Colias, 2017).

Technology breakthroughs are also taking place at the "nano" scale. Consider two materials that will soon impact product design—and maybe even enable future computing power.

1. **Carbon Nanotube Technology (CNT).** CNT is making its way into commercial application. It has been a decade since the first bike frame (weighing only 2.1 pounds) was made using CNT. More importantly, Stanford engineers have built the first CNT computer, noting that CNT may be a viable successor to the silicon transistor. CNT promises smaller, more energy efficient processers—a key to perpetuating Moore's law and continued growth in affordable computing power. Stanford Professor H. S. Phillip Wong noted, "CNTs could take us at least an order of magnitude in performance beyond where you can project silicon could take us" (Abate, 2013);

2. **Graphene.** Graphene—a honeycomb structure of graphite a single atom thick is 200 times stronger than steel, far more flexible and stretchable than silicon, and a conductor of both heat and electricity—has been identified as a "miracle" material (Naik, 2013). Companies are using graphene in anti-rust coatings, batteries, computer chips, DNA-sequencing devices, flexible touch screens, and tires. Graphene's most unique impact could be in high-speed electronics and flexible circuitry. Consider two possibilities.

- **Sensor Technology.** Graphene could revolutionize medical care as graphene-based sensors are woven into clothing to capture and communicate real-time biometric and biomechanical health data;
- **Transportation Industry.** Graphene could make electric vehicles—including solar-powered planes and semis—economically viable.

The bottom line: materials science is not just changing product innovation. New materials are altering supply chain processes, promising to redefine the total cost equation that establishes the boundaries of competitive markets and molds economic development.

3.8. Robotics

Robotics had captured the imagination of popular culture and businesses alike since the industrial revolution. Although industrial robots have been used for decades to perform repetitive tasks that required strength and precision beyond human capabilities, machines have never possessed human dexterity or mobility. That limitation is diminishing. In 2017, Boston Dynamics successfully created a bipedal, humanoid robot that can not only jump from platform to platform in succession, but also perform backflips (Simon, 2017). From a purely practical standpoint, Amazon is closing in on the holy grail of robotics: Developing robots that can imitate the human hand and are able to pick odd-sized items from a warehouse bin or shelf (Garfield, 2016). The future of robotics in SCM is evolving in two directions.

1. **Workforce Enhancement.** As the fastest-aging industrialized nation, Japan faces a serious shortage of productive workers. Sixty year olds possess neither the strength nor the stamina of a younger worker. The solution: Employ exoskeletons to help retain aging but skilled employees who would otherwise need to retire or seek out a less-intensive job (Wall & Ostrower, 2016). Similarly, Ford has begun pilot tests of EksoVest, an exoskeleton designed to minimize fatigue and repetitive stress injuries, among its manufacturing plant workers (Strickland, 2017). The ultimate goal of incorporating robotics to enhance worker capabilities is to meld worker experience and cognitive skill with robotic strength and endurance;
2. **Workforce Replacement.** Exoskeletons extend worker longevity, but they are not a complete response to the labor shortages emerging in Japan (MacFarlane, 2017) and China (Burkitt, 2016). Fully automating work via robotics is thus taking on a more prominent role in process design, replacing human workers in areas characterized by either exceptionally high labor costs or a very shallow labor pool (Sirkin et al., 2015). For instance, recent minimum wage increases in San Francisco motivated CaliBurger to deploy Flippy, a robotic chef, to replace its burger cooks in restaurants in 2017 (Heater, 2017). Beyond reducing labor costs, properly maintained robots promise to limit quality problems introduced by human error, such as unsanitary worker actions that resulted in numerous norovirus outbreaks at Chipotle locations (Rettner, 2017).

Boston Consulting Group estimates that the hardware and software costs required to introduce robotics into the workplace will continue to decline over the next decade. As robotic capabilities expand and costs decrease, more companies will find it economically attractive to integrate robotics into more supply chain operations. Some pundits fear that robots will replace workers on a massive scale, creating endemic unemployment—a problem potentially worse than an aging workforce (Manyika et al., 2017). Indeed, robotics might displace the path to industrialization for millions of workers in less developed countries across Africa and Asia. Such fears are likely overblown as robotics is poorly suited for situations where complex judgment is required and robots are a poor substitute for labor where production volumes are low. Ultimately, the question remains, “How, and how well, will humans and robots co-exist in future supply chain design?”

3.9. Virtual reality

From the 1960’s Sensorama to 2017’s Oculus Rift, virtual reality (VR) has traveled a circuitous path to market. Today, immersive imagery on sleek and portable machines has replaced clunky graphics and expensive, cumbersome hardware. Yet, consumers have not embraced virtual reality, favoring augmented reality (AR) instead (Economist, 2017). For instance, Volkswagen developed an AR-based service app that enables technicians to see precisely what tool to use and the exact steps to complete repairs, dramatically reducing error rates (Jaynes, 2013). Together, AR and VR startups attracted over $2.5 billion in venture capital in 2017 (Digi-Capital, 2017) as companies explore opportunities to immerse users in a digital environment or to augment reality with digital overlays.

1. **Real-Time Contextual Information.** Augmented reality enables guided learning. At DHL, warehouse workers wear a head-mounted display (HMD), which shows a digital pick list with precise location and best routes inside the warehouse. When workers arrive at their destination, image recognition software automatically scans and confirms their picks—or guide them to the correct item if their initial destination is incorrect. This AR-enabled process is not just fast but it also helps eliminate errors—which cost the typical warehouse over $389,000 annually due to mispicks (DC Velocity, 2013). Providing real-time, contextual information to supply chain workers translates to reduced training costs, increased quality, and accelerated product flow and service velocity;
2. **Immersive Virtual Collaboration.** Effective collaboration has always required team members to meet face-to-face (Kirkman et al., 2004). Today, AR and VR are beginning to simulate real-life interaction among collaborators that might be half a world away. For example, Microsoft's HoloLens enables members of a supply chain to see stand-alone holograms of colleagues in the same room, creating a pseudo face-to-face collaboration without costly and potentially disruptive travel. The HoloLens creates more lifelike immersion as it allows users to interact with a 3D presentation of a flat illustration;
3. **Customer Engagement.** For many retailers, their selection of merchandise far exceeds the available physical display space, limiting customers' ability to interact with specific items. Brick-and-mortar retailers like Best Buy take advantage of this reality to reverse "showrooming" and encourage customers to research online but purchase in store (Fawcett et al., 2017). Today, Apple's iOS11 and its ARKit software has made it easy for retailers to develop AR apps. Retailers like IKEA, Wayfair, and Houzz now place thousands of 3-D images online that consumers can capture with their smart phones and then position virtually in the physical space they might inhabit. Customers can even walk around the item to see the 360 view. Houzz says that customer who engage with the AR tool are 11 times more likely to buy items they model in their homes (Bliss, 2017).

Albert Einstein noted: "Reality is merely an illusion, albeit a very persistent one". So, what happens when we are able to create an illusion that is so realistic and persistent, that it successfully immerses us in an environment that does not really exist? For companies, the challenge—and opportunity—is to figure out how to leverage these reality-bending technologies to create relevant and meaningful experiences that enable workers and customers to make faster and better decisions.

4. Implications for 21st-century supply chain design

Each of the technologies discussed above possesses the potential to be a trigger point to a punctuated equilibrium environment. However, experience argues that many, if not all, of the technologies will go through a more gradual adoption process as companies figure out the boundary conditions for effective implementation—that is, when and how they can create meaningful value. However, the convergence of so many diverse, yet inter-related technologies complicates the process of separating the real game changers from the distractions. Forecasting the future becomes a NP-hard problem. Indeed, the long-awaited and oft-predicted factory of the future could soon be reality. But, factories might not be the only facilities running with lights out and without employees. Think about the possibilities for warehouses and ports. Alternatively, tomorrow's supply chains could conceivably operate without factories or warehouses. The one certainty for supply chain strategists is that the Internet of Things and the shared economy will change both company capabilities and customer preferences.

Companies that misread, or simply miss, the import of today's game changers will evolve their strategies and supply chain networks too slowly. These companies will die. By contrast, companies that overreach and invest too heavily—or incorrectly—in a new technology that is early in the hype cycle risk dissipating scarce resources. In today's intensely competitive and dynamic environment, these companies may be so weakened by inappropriate investments that they lose the competitive battle. Indeed, a critical aspect of getting supply chain design right is to anticipate the timing of trigger points. First-mover advantages are invaluable—not just because they are real but also because they cannot be replicated. It is hard to imagine a host of Amazons emerging as major players in online retailing. But, getting into a new game too early can be disastrous. Toshiba's bet on HD-DVDs proved ruinous for its entire home entertainment business when consumers chose Blu-ray over HD-DVD. Betting on technology-induced change that does not come to pass, or that emerges more slowly than anticipated, precipitates a short life cycle (a real threat to Tesla, especially if cash runs out before a viable supply chain is built). From this perspective, evolution theory offers three caveats that merit academic investigation.

1. **Avoid the Front End of the Hype Cycle.** Decision makers need to discern between hype and reality. They need to be able to evaluate the ultimate shape of the technology adoption curve. This capability will enable managers to build real, meaningful, and distinctive capabilities—without lost time or wasted money. Even incremental

improvements here could confer competitive advantage. The research question is, "Under what circumstances does a technology become a trigger point to a punctuated equilibrium environment?";

2. **Cultivate an Evidence-based Decision-making Environment.** The reality is that many decision makers don't fully consider the downside of following the hype. They do not employ the system thinking and total costing needed to comprehensively evaluate emerging technologies and their competitive impact. Perhaps more important, many managers make decisions out of fear rather than based on valid capability analysis. That is, they fear being left behind if a punctuated-equilibrium environment actually emerges. More behavioral research is needed to understand this behavior and help organizations structure hiring, training, and measurement practices to cultivate an evidence-based decision-making environment;
3. **Adopt a Socio-Technical/Socio-Structural Approach.** Tracking technological feasibility is necessary but not sufficient to getting timing right (Fawcett et al., 2011). Understanding what is socially and structurally acceptable is needed. For instance, Blockchain is technically viable, but are suppliers ready to trust buyers with so much transparency. Similarly, several companies have shown that autonomous vehicles are feasible, but are the risks of being hacked too great to bring the technology to market? More holistic research that takes into account the socio and structural ecosystems is needed to evaluate and define the technology adoption cycle.

4.1. A metaphor for purposive supply chain design

Beyond the research related to evolution theory and technology adoption, the supply chain discipline needs more targeted research on how each of the potential game changers might influence supply chain design. To provide guidance on the types of research needed, we turn to the results of 20 years of inductive field work, which identified an appropriate metaphor for proactive supply chain design—specifically, the professional sports general manager. The general manager's (GM's) job—like that of the supply chain professional—is to assemble the right players and help mold them into a team that can win in the context of constantly changing competitive rules. Specifically, the GM must perform three inter-related tasks.

1. **Discern the Competitive Rules.** In sports, as in the business world, the "unwritten rules" are always in flux. There are two ways to win a championship. One option is for the GM to clearly discern the rules of the game and then execute better than other teams. The alternative is to identify an opportunity to redefine the rules of the game, placing other teams at a competitive disadvantage—at least until they can rebuild their teams. Redefining rules typically provides a more enduring competitive advantage. That is why both the Golden State Warriors and fast-fashion retailer Zara choose to compete in their respective arenas at an up-tempo pace that rivals simply cannot match;
2. **Team Composition: Assessing Readiness.** As GMs grasp existing rules and how they can influence the game's evolution, they must assess their own team's readiness to compete and win. Readiness assessment begins as GMs ask several key questions:
   - What does our team do well?
   - Do we possess any unique advantages?
   - What skill gaps do we face?
   - What complementary capabilities do we need the most?

The answers to these questions provide the insight needed to conduct a successful player draft. Success is defined by how well the GM closes the team's capability gaps.

To find the right players, GMs must assess each player's readiness to play—that is, how well the player can contribute to the team's ability to win (now and in the future). Gauging player readiness involves hours and hours of watching film, interviewing players, talking to former coaches, and running drills. Reams of data are collected, collated, and compared. The goal: Map each player's capability profile to team needs to forecast how well the player will help the team win. For example, readiness assessment led the Golden State Warriors to sign Kevin Durant as a free agent. Likewise, a meticulous readiness assessment led Apple to buy Siri, Beats, and Turi in order to close key technology gaps and make the HomePod possible.

3. **Team Chemistry: Instilling Identity.** Having the right players in the right roles guarantees that a team looks good on paper. But, looking good on paper does not guarantee the team will win once the game begins.

To turn talent into championships, GMs need to invest in team chemistry. Critically, chemistry derives from trust and it promotes identity; that is, a unique and persistent way of doing things. The Golden State Warriors possess both chemistry and identity—a reality that prompted Kevin Durant to want to join the Warriors even though teams across the NBA competed for his capabilities. Honda has cultivated the Honda Way—a way of doing business that has made Honda a customer of choice for many of the best suppliers in the auto industry.

To summarize, the metaphor of the GM—that is, the quest to build a championship team—illustrates the key steps in purposive supply chain design (see Figure 3). Critically, each potential game changer promises to influence all three phases of purposive supply chain design.

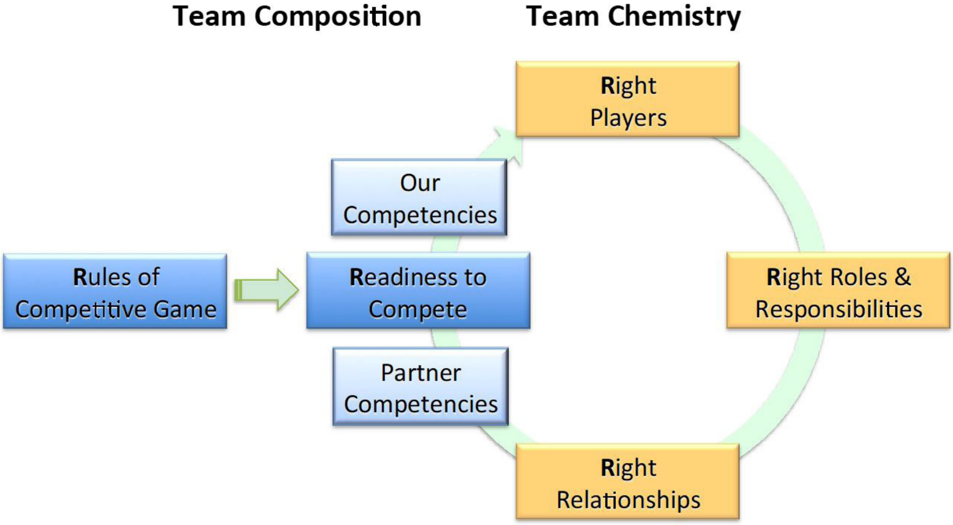

Figure 3. The 5Rs of purposive supply chain design.

4.2. A typology for supply chain design research

As we identified some ways each technology disrupter may change the rules of the competitive game as we introduced and described each technology, we focus below on a two-by-three typology that relates purposive supply chain design to the three core value-added processes that supply chain management is responsible for designing and managing: product development, order fulfillment, and service delivery (Fawcett & Waller, 2012). Importantly, we identified nine potential technology game changers. Thus, a typology with just one research question per technology per cell would include 54 research questions—and that would be just a start to identifying potential research opportunities.

The goal of Table 1 is thus to merely exemplify the types of research needed to help decision makers design the 21st century supply chain. Given the nature of the emerging technologies, the number of questions related to how to identify, develop, and co-mingle the right capabilities to build a winning supply chain team is limited only by the researcher's imagination. Indeed, the new technologies could enable unprecedented levels of supply chain collaboration, if companies can figure out how they can positively impact composition and chemistry. From this perspective, it is important to note that many research questions relate to the change management as well as the human-technology interaction. Thus, future supply chain research will need to incorporate more longitudinal analysis and will require more holistic inductive, behavioral, and even neurochemistry/neuroscience-based research methods.

To survive, companies need astute scanning and dynamic scenario analysis to discern and define the new competitive rules—and the new capabilities that are needed to win. Amazon, for instance, still has not figured out the capability or the infrastructure issues needed for profitable last-mile delivery. To thrive, thought leaders will go a step further. Rather than merely trying to predict the future of Industry X.0, they will take a purposive approach to supply chain design so they can help create it. Such an approach takes a page from the Jeff Bezos' and Elon Musk's game plan. Thought leaders will leverage purposive supply chain design to win beyond the hype as they put in place supply chains that can keep pace with and propel visionary business models. Ultimately, we

Table 1. A typology for how technology will disrupt purposive supply chain design.

Purposive Supply Chain Design	Product Development	Order Fulfillment	Service Delivery Experience
Composition	• How can big data be used to evaluate bleeding-edge capabilities and thus the right partners for early supplier involvement in new product development? • How will emerging technologies change the total cost equation? Further, will they make refined (i.e., TCO and ABC) costing viable tools?	• How can companies instill the new capabilities required to add value as new business models evolve? What does an agile response capability look like in a digital world? • As new technologies emerge, how will companies assess and close capability gaps? Will the make/buy and disintermediation decisions evolve? • How will technologies extend the reach of global supply chains?	• How can companies bundle emerging technologies to increase customer engagement and create customer-pleasing service experiences? • How will robotics change downstream, customer-facing supply chain design?
Chemistry	• How do emerging technologies including big data, AI, and VR enable companies to obtain immersive feedback to design more customized products? Does customer immersion raise customer expectations? • How will the new technologies influence discontinuous supply chain design? Will they alter the buyer/supplier relationship continuum?	• How do virtual interactions influence the development of trust and chemistry? Are they more or less effective than face-to-face contact? • How do socio-relational factors influence partner willingness to adopt blockchain et cetera?	• How can new technologies leverage the other Es—i.e., entertainment and education—in a digital economy? What are the boundary conditions for virtual customer integration? • How will information security concerns impede new service business models—e.g., AI and IOT in customer-order models?

need much more nuanced research to help managers make sense out of the chaos of today's emerging game changers so that companies can begin to build tomorrow's supply chains today.

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