Chapter 5 Understanding Supply Chain 4.0 and its potential impact on global value chains

CHAPTER 5

Understanding Supply Chain 4.0 and its potential impact on global value chains

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ABSTRACT

The reorganization of supply chains using advanced technologies, such as the Internet of Things (IoT), big data analytics, and autonomous robotics, is transforming the model of supply chain management from a linear one, in which instructions flow from supplier to producer to distributor to consumer, and back, to a more integrated model in which information flows in an omnidirectional manner to the supply chain. While e-commerce is uniquely suited to many of these techniques, they also hold the promise of improving efficiency in brick-and-mortar stores. These technologies are generating enormous benefits through reducing costs, making production more responsive to consumer demand, boosting employment (employment in supply chain sectors where such technologies are most likely to be applied has grown much more rapidly than in other supply chain sectors and in the economy as a whole) and saving consumers' time. The impact of these technologies on the length of supply chains is uncertain: they may reduce the length of supply chains by encouraging the reshoring of manufacturing production to high-income economies, thus reducing opportunities for developing countries to participate in GVCs, or they may strengthen GVCs by reducing coordination and matching costs.

- Digital technologies are transforming supply chain management from a linear model in which instructions flow from supplier to producer to distributor to consumer, and back, to a more integrated model in which information flows in multiple directions (sometimes referred to as Supply Chain 4.0).
- Digital technologies offer huge benefits in terms of inclusive patterns of growth, innovation and entrepreneurial opportunities
- The impact of new digital technologies on GVCs is uncertain: they may reduce the length of supply chains by encouraging the reshoring of manufacturing production, thus reducing opportunities for developing countries to participate in GVCs, or they may strengthen GVCs by reducing coordination and matching costs.

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1. Introduction

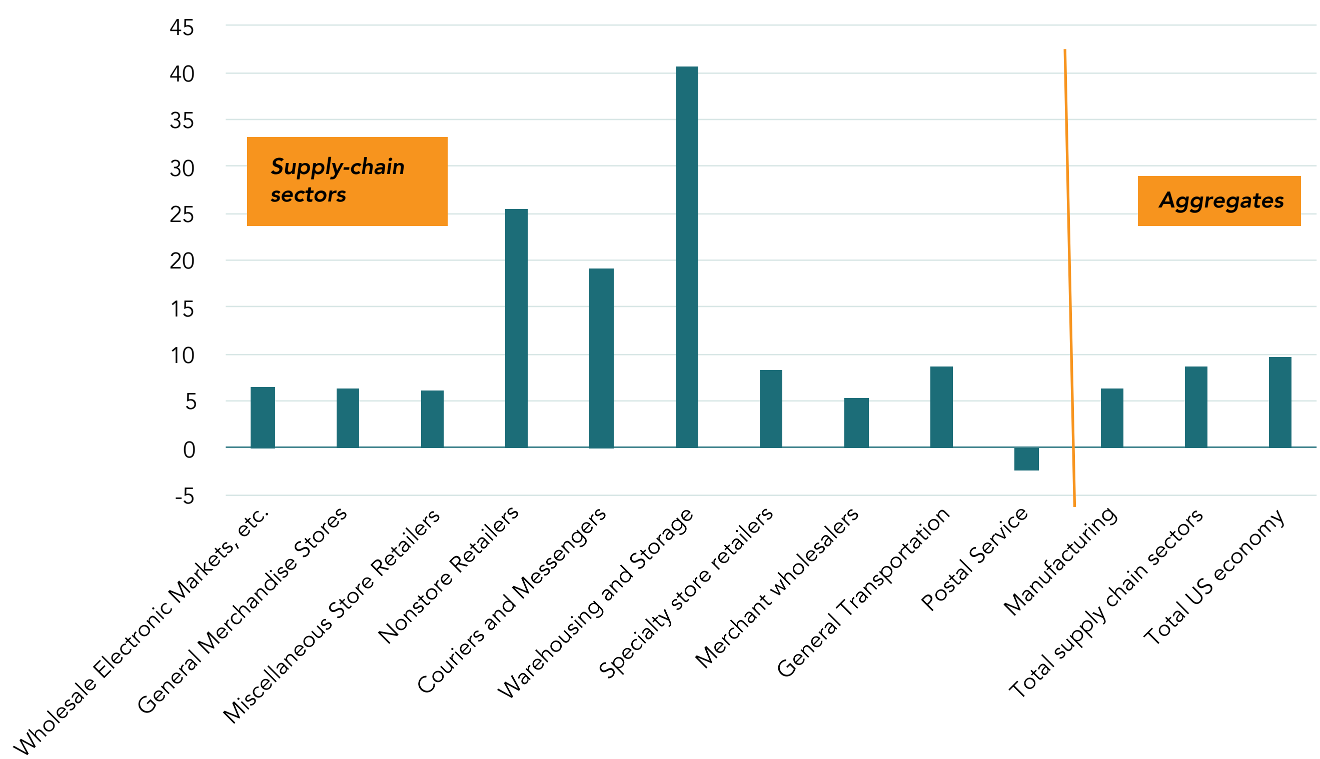
"Supply Chain 4.0" is the re-organization of supply chains – design and planning, production, distribution, consumption, and reverse logistics – using technologies that are known as "Industry 4.0". These technologies, which emerged in the 21st century, are largely implemented by firms that are at the frontier of supply chain management in high-income countries. Though, as we will argue, this classification is somewhat artificial, it does in fact capture certain prevailing ideas about what firms need to do, and are doing, in order to maintain competitive supply chains.

1.1 Supply Chain 4.0 is here already

While much of the literature we will review is forward-looking, and indeed has emerged only in the last two or three years, almost all of the technologies we discuss are being implemented today, at least by firms at the frontier of supply chain management, which by and large are in high-income countries.[1] With only one or two exceptions, everything described in this chapter is already being applied in actual supply chains, or is at least being piloted. While the literature includes many ideas for emergent technologies that might be available by 2030 (for example, vast fleets of self-driving delivery vehicles, or the "smart mirror" in the local clothing store that supposedly will allow you to virtually try on clothes just by scanning their bar codes), this argument does not depend on the deployment of technologies that do not really exist yet. The diffusion of already existing Supply Chain 4.0 technologies will already have a substantial impact.

When we say that Supply Chain 4.0 is here, we mean that it is here at the frontier of supply applications and being more widely adopted, not that it is universal. Even in high-income countries, the principles of Supply Chain 4.0[2] are unequally applied. Advanced supply management techniques are more likely to be observed in sectors such as electronics where earlier waves of management techniques took hold first, or in big-box retailers such as Walmart. As recently as February 2018, supply chain problems caused two-thirds of the 900 Kentucky Fried Chicken restaurants in the United Kingdom to close because they had run out of chicken.[3]

FIGURE 5.1 US employment by sector, supply chain sectors, manufacturing, transportation, post office and other, percent change (2011-2016)



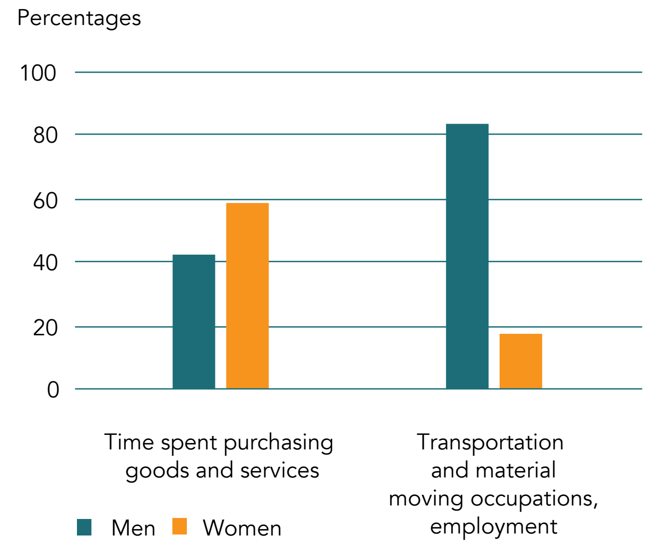
1.2 It transforms business models, making supply more customer-driven

While Supply Chain 4.0 involves the deployment of such contemporary tools as the Internet of Things (IoT), big data analytics, autonomous robotics, and the like, it is not really about any of these things. It is about transforming the model of supply chain management from a linear model in which instructions flow from supplier to producer to distributor to consumer, and back, to a more integrated model in which information flows in an omnidirectional manner to the supply chain. While lead firms are increasingly analyzing this information through "supply chain control towers," the end effect of this development could be making the goods economy more responsive to consumer demand.

1.3 E-Commerce is ideally, but not uniquely, suited for Supply Chain 4.0

The ability to capture data in e-commerce empowers many of the data-driven methods we will discuss. In particular, older technologies (electronic data interchange) were already gathering large amounts of information in business-to-business (B2B) e-commerce, which can be used to improve supply chain performance. At the same time, most of the developments discussed here can be used to improve the performance of traditional brick-and-mortar stores, where the large majority of retailing still takes place, as well as in an e-commerce setting.

FIGURE 5.2 Shopping and e-commerce occupations, gender division (2017)



Source: BLS American Time Use Survey, BLS Current Population Survey, and authors' calculations.

1.4 It generates jobs, which substitute for household labor and promote human well being

In an exercise using U.S. data gathered in the Occupational Employment Statistics of the Bureau of Labor Statistics, this study shows that employment in the most dynamic parts of the supply chain has grown at a rate substantially exceeding that of the overall economy since 2011. These sectors include warehousing and storage (used by all retailers, Walmart as well as Amazon), couriers and messengers (the sector including UPS and Federal Express, commonly known as "express carriers"), and non-store retailers (particularly electronic shopping and mail-order houses, the sector inhabited by Amazon and eBay) (see Figure 5.1). Most of the jobs being created involve moving goods around either in warehouses or delivery vehicles and have many of the characteristics of factory work. Though robots are used in many of these applications, they appear, at present, to be complementary with human labor.

Most importantly, e-commerce, powered by Supply Chain 4.0, involves a great substitution of market labor for household shopping time. Traditional shopping is a time-consuming and, for many, tedious activity. Because household time is an intrinsically scarce resource, Supply Chain 4.0 is already having profound impacts on human well-being. However, time saved as a result of e-commerce also has increased employment in the transportation and material moving occupations. As shown in Figure 5.2, men account for 42 percent of the time spent shopping, while women account for 58 percent, whereas men account 82 percent of employees in transportation and warehousing jobs, while women account for 18 percent. As discussed further in section vi below, these workers, concentrated primarily in warehouses and express delivery companies, are paid to do the picking, packing, and driving that would otherwise be done by household shoppers in the absence of e-commerce.

1.5 It can transform the operation of global value chains

Whether conceived of as an advanced management practice, or simply as a cluster of technologies to be deployed by advanced management practices, Supply Chain 4.0 provides substantial opportunities for firms to enhance productivity, profitability, product quality, and performance in international trade. Because Supply Chain 4.0 diffuses at an unequal rate, it can also influence the size distribution of firms within industries as well as income distribution across countries. The enhanced ability to track both physical and financial information also has implications for activities of government which depend on highly disaggregated firm data, such as tax enforcement and monitoring of rules of origin in international trade.

2. The impact of Supply Chain 4.0 on firms

2.1 Technologies and management strategies

One way to approach Supply Chain 4.0 is to treat it as simply the application of Industry 4.0[4] to the supply chain.[5] And a common way to approach Industry 4.0 is to treat it as simply a bundle of technologies that have emerged, or are emerging, in the 21st century (see Figure 5.3). Then the task might be simply to map the technologies in Industry 4.0 to each of the steps of the supply chain – design and planning, production, distribution, and consumption.

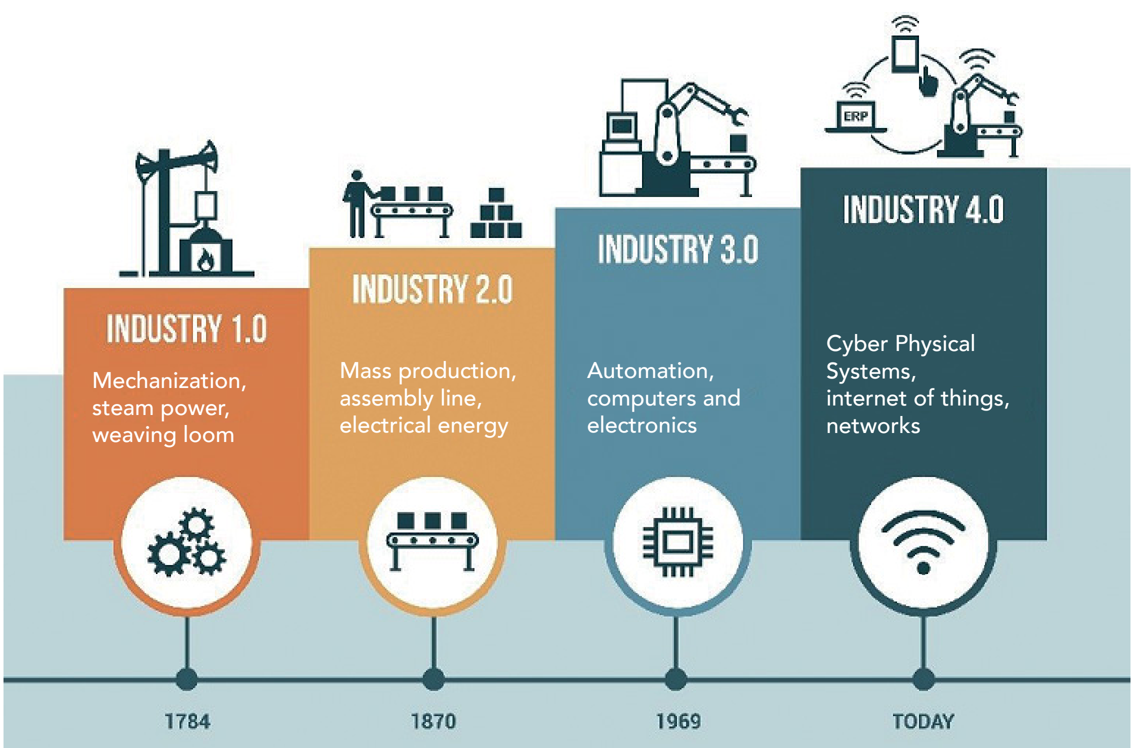
While each of the "industrial revolutions" is generally characterized by a cluster of typical technologies, the list of these technologies varies from one author to another. Cirera *et al.* (2017) identify 17 technologies that are said to characterize Industry 4.0 (see Figure 5.4), which are referenced two or more times in a corpus of underlying sources, of which the most frequently mentioned are the IoT; big data analytics; 3D printing; advanced (autonomous) robotics; sensor-using smart factories[6]; augmented reality[7]; artificial intelligence[8]; and cloud computing[9]. Pfohl *et al.* (2015) identify over 50 technologies associated with Industry 4.0, mind-mapped to such underlying attributes as "digitalization" (which applies to everything), "mobility", "modularization," "network collaboration," "autonomization", "transparency," and "socialization".

It is tempting, as noted above, to attempt to understand Supply Chain 4.0 as the application of Industry 4.0 to supply chains, and then to map each of the stages of the supply chain (planning and design, production, distribution, consumption, reverse logistics) to one or more of the iconic technologies said to be typical of Industry 4.0: the IoT, cloud computing, artificial intelligence, etc. The difficulty immediately arises that the application of technologies to sets of problems is fluid, and it takes a long time to determine what the most successful technologies will be in any given area. For example, during 1880-1920 it was not at all obvious how three available forms of energy, steam, electricity and gasoline, were to be applied to two areas of activity, factories and motor vehicles. Eventually a consensus emerged that factories ought to be run by electricity and motor vehicles by gasoline, but not before every other combination of power and activity had been experimented with extensively, and with some success (Freeman and Soete 1997 75-80, 139-140).

Fortunately, there is a more fruitful way to approach the problem, because the broad functional outline of how Industry 4.0 affects supply chains is already apparent.

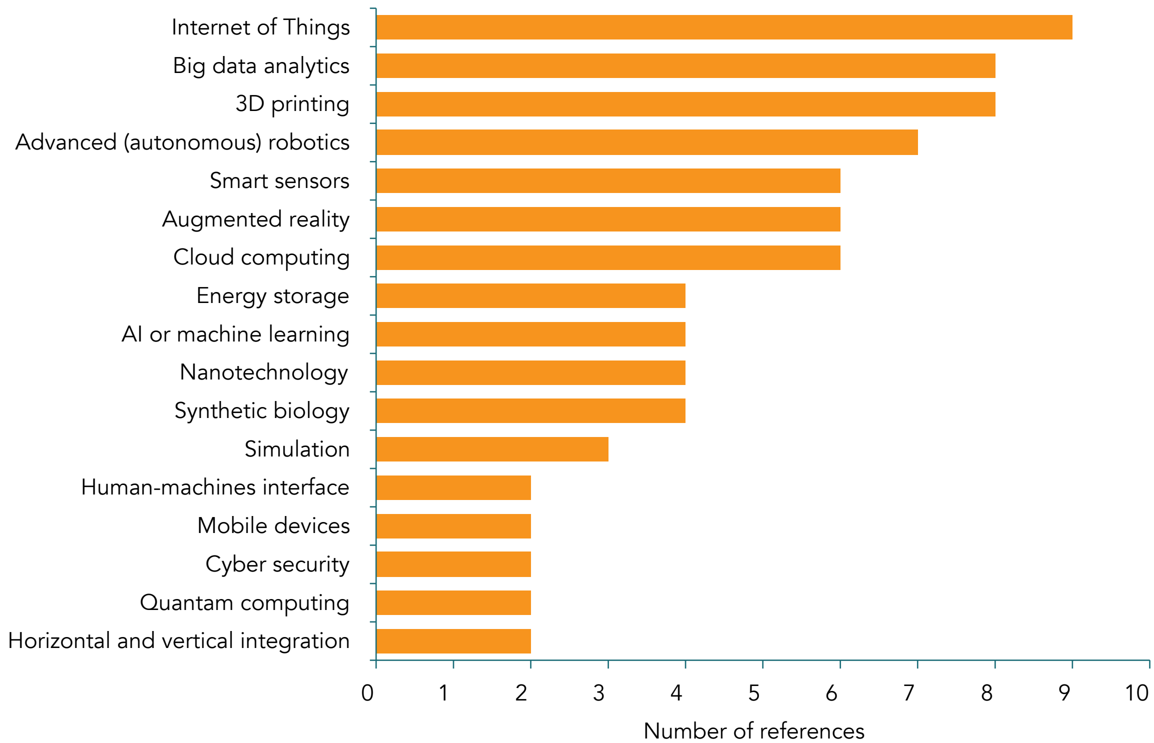
Supply Chain 4.0 fundamentally changes the way information flows through the supply chain. Traditional supply chains link suppliers to customers in a linear manner, with each firm sourcing inputs from suppliers and in turn delivering its products to customers (Figure 5.5). The planning process of each firm is designed to ensure that deliveries are coordinated with the customers' sourcing activities, and that sourcing activities are coordinated with the suppliers' delivery activities, and that returns of unwanted or unneeded products are accounted for (PWC 2016b). The processes by which this is done have been codified in the Supply-Chain Operations Reference (SCOR) model, originally developed in 1996 by the management consulting firm PRTM

FIGURE 5.3 The currently fashionable model of Industry 4.0 is over-simplified, but it reflects current thinking about what's happening now (2018)



Source: https://www.hammelscale.com/industry-4-0/

FIGURE 5.4 Industry 4.0 technologies, by relative emphasis in recent studies

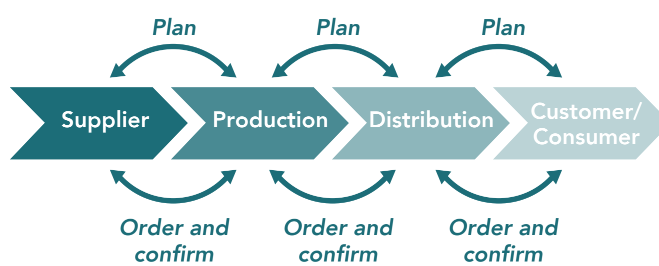


Source: Graphic from Hallward-Driemeier and Nayyar (2017).

(now part of PriceWaterhouseCooper) and AMR Research (now part of Gartner) (Lambert 2008, p. 305), and are now part of a de facto standard strategic, management, and process improvement methodology for supply chain management. The ideas behind SCOR, and their implementation, have been important for the development of global value chains and for supply coordination among networks of firms.

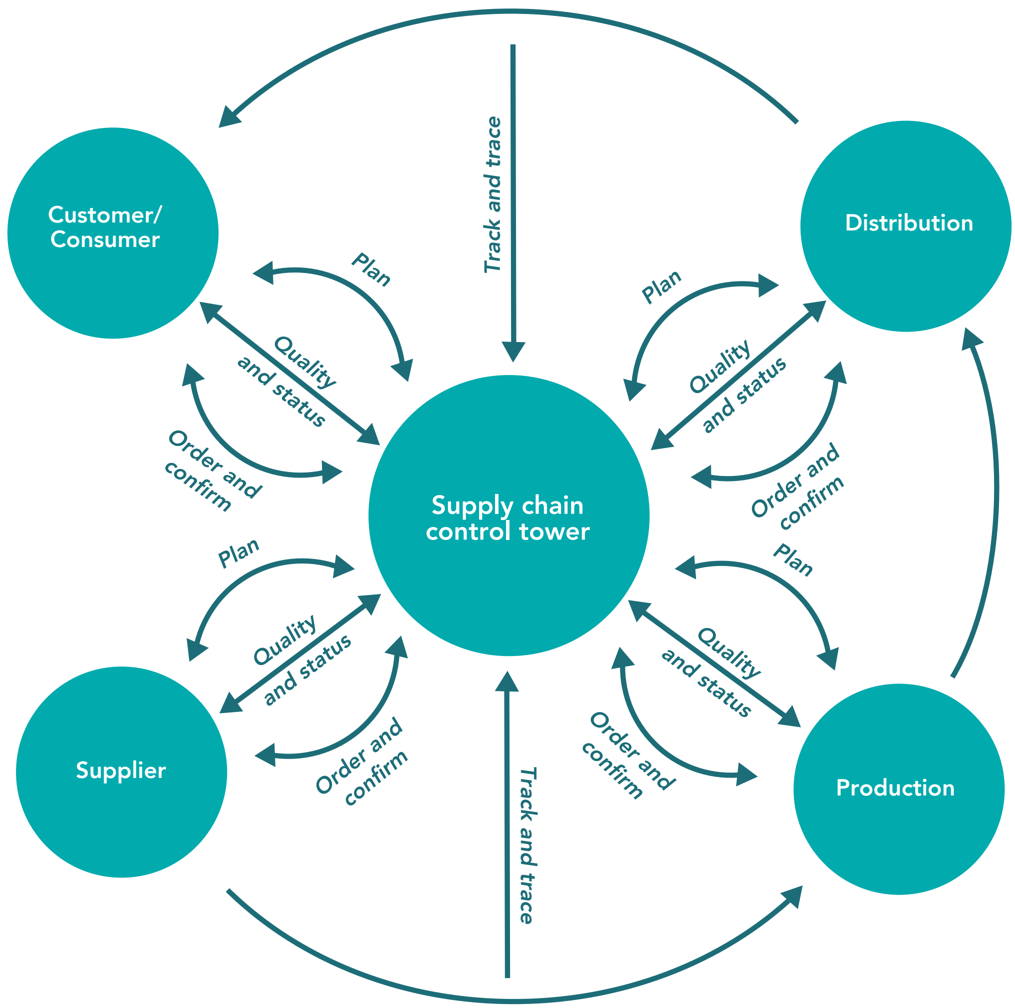
As successful as this method of supply chain management has been, it has limitations. Flows of information tend to primarily link each firm to its immediate suppliers and customers, not to firms further down the chain. In supply chains with multiple links, this leads to delays in the processing of information. In particular, changes in the system flowing from changes in final demand, which are often unpredictable, become distorted as they pass upstream, analogous to the old child's game in which a message whispered from one player to another becomes more and more different from its original content. Even with a lead firm acting as "impresario" of a network of firms, one actor is unlikely to have full information about everything that is going on in the supply chain. Managers at Walmart, planning for the fall apparel season, are in some sense leaders of their global supply chains (USITC 2011, 3-33 ff). But they are unlikely to actually know what is happening in button and zipper factories in Bangladesh which are part of their supply chain. That information is held by middlemen. Firms in Singapore, which ship small screws to manufacturers of disk drives in Thailand, which are in turn shipped to assemblers of laptop computers in China, cannot see changes in consumer demand visible to Best Buy, a retailer in the United States (Hiratsuka 2005). The term Supply Chain 4.0 can be usefully applied to an integrated supply chain ecosystem, in which information flows in all directions, analytics enable adjustment throughout the supply chain, and response takes place in real time (PWC 2016b) (see Figure 5.6).[10] To rapidly assess and respond to changes in

FIGURE 5.5 Traditional supply chain model



Source: PWC 2016b.

FIGURE 5.6 Integrated supply chain ecosystem



Source: PWC 2016b.

customer demand, tracking and tracing throughout the supply chain is enabled through sensing technologies underlying the Internet of Things (IoT), including radio frequency identification (RFID), Bluetooth, and GSM (global system for mobile communication), which links maritime transport to satellites. In particular, changes in customer demand can be rapidly assessed and responded to. This technology has had a wide uptake. According to a recent PwC study on the rise of Industry 4.0, a third of the more than 2,000 respondents say their companies have started to digitize their supply chains, and fully 72 percent expect to have done so five years from now (PWC 2016a, p. 11).

2.2 Big data and supply chain analytics – running scenarios from a supply chain control tower

New technologies gather prodigious amounts of data. In the last decade, the cost of bandwidth has decreased by a factor of nearly 40 times, processing costs have declined almost 60 times, and many of the sensors used in IoT technology cost no more than 60 cents (CGI 2016). These data are only useful if they can be reduced to information useful for making decisions in real time that create business value. Big data analytics thus are about using data to drive useful business intelligence, answering the questions, "What just happened?", "Why did it happen?", and "What are we going to do next?". Specific applications of big data analytics include early warning algorithms (are we about to run out of something or hit a bottleneck? Did prices we care about just rise?), predictive algorithms (what is demand likely to look like next spring, or five years from now?), stock-keeping unit (SKU) rationalization (the decision about the optimal set of products, or SKUs, to offer to consumers at any given time), channel assessment (the decision about the optimal way to get product to end market, e.g. e-commerce/

distributors/company-owned outlets/large and small retailers/mail-order/etc.), and dashboards (user-friendly quick visualization in "supply chain control centers"). The ability to collect and analyze data gathered in the whole supply chain makes it possible to "run scenarios within the platform" (PWC 2016b), where the platform is conceived of as an overarching software solution within the supply chain control center.

The desire to collect and distribute data rapidly across a supply chain explains much of the recent enthusiasm for blockchain technologies in the context of supply chains (Petersen *et al.* 2017). Blockchain is a distributed ledger technology that allows multiple parties to maintain copies of the same information in different locations, either in an open manner or requiring individual entities' permission to access the network. Blockchain protocols encode information such as numbers or programs, time-stamp them, and enter them as a block into a continuous chain of previous blocks linked to the same transaction (Niforos, Ramachandran and Reherman, 2017). Such attributes make blockchain attractive for supply chain management, as well as for other uses such as fintech, cryptocurrencies, smart contracts, and security. Blockchain technology also has potential application in port logistics, improving tracking and tracing of containers and coordination among the diverse actors in ports such as carriers, ship agents, terminal operators, insurers, customs agents, financial institutions and inland transport (Weernink *et al.*, 2017). While there is a great deal of hype about blockchain and supply chains at the present moment, pilot projects involving establishing origin of Australian oats, preventing counterfeiting of Italian wine, combating fraud in diamond markets, and tracing the provenance of geological samples have demonstrated proof-of-concept (Petersen *et al.* 2017). It should be noted that many of these coordination functions can be performed by combinations of technologies that do not involve blockchain.

2.3 Smart factories/fractal factories/M2M communications/driverless programmable vehicles

Improved data gathering within the IoT, combined with analytics, enables process optimization within the factory as well, in order to enable timely business decisions. The application of Supply Chain 4.0 within manufacturing facilities is sometimes referred to as the "smart factory" (Pfohl *et al.* 2015). Embedded data collection units, using both automatic identification and data collection and radio-frequency identification (RFID) technologies, can be embedded in most pieces of factory equipment. The information can be passed from machine to machine (M2M) and handed to a supply chain control tower for decision making. Autonomous robotics simply refers to the control and reprogramming of robotics using bilateral and multilateral machine communication. Intra-logistics within factories includes the use of driverless vehicles to move materials based on externally-provided information.

One of the most important features of the Smart Factory is the ability to do predictive maintenance. The use of sensors to identify maintenance needs in advance of potential breakdowns reduces maintenance costs. (CGI 2017) For example, Microsoft and CGI developed a smart-sensor based solution for a company that maintains more than 1.2 million elevators worldwide. Information from the sensors is made available to service technicians and their supervisors through cloud-based dashboards. Manyika *et al.* (2015) estimate that predictive maintenance using IoT can reduce maintenance costs of factory equipment by 10-40 percent and reduce equipment downtime by up to 50 percent. Similarly, the use of predictive analytics and IoT can have a big impact on energy maintenance, both by using energy consumption data to detect potential equipment failures and by continuously modifying equipment settings and process parameters in real time (CGI 2017).

2.4 Smart logistics and the warehouse of the future

Smart logistics encompasses not only scheduling of transport, but also activities within the warehouse. It is within the warehouse that many of the most profound changes are already taking place. As noted above, one of the big changes is that the warehouse and the customer become more visible to each other, so that customer final purchases trigger not only product moves from the warehouse but also product moves from the manufacturer to the warehouse.

In e-commerce, the Internet makes the warehouse visible to the customer. A familiar example of this is the notice one encounters at Amazon.com, "Only three left! Hurry!", which can be used to influence both consumer behavior and trigger re-stocking. At Taobao.com, the giant Chinese e-commerce platform, customers are presented with both inventory and sales data for products. Alibaba is another platform that functions as the architect of an increasing complex eco-system, that includes designers/entrepreneurs, marketers, payments, financing (credit) logistics suppliers, integration of on- and offline retail, supply chains and manufacturing, all of which are complementary players in the eco-system interacting on the network, in rapid-response, data-driven, algorithm-guided mode (Spence, 2018).

The predictive maintenance techniques discussed above can reach into the warehouse as well, which can similarly optimize delivery of spare parts to factories. Indeed, with a flexible 3D printer, spare parts can be produced in the warehouse, triggered by demand. Some analysts project that 3D printers, which can be placed in any environment including delivery trucks, may make warehouses obsolete.

A traditional warehouse involves a good deal of "pick and pack" activity. Employees search around in the warehouse for products that have been ordered, take them off the shelves, and pack them. If the warehouse serves several firms, the packing may involve selecting packing materials marked with the logo of a particular firm. Clearly knowing where the products are located in a large warehouse, and moving through the warehouse in a time-minimizing manner, can speed up delivery time substantially and reduce errors. Within the warehouse, autonomous logistics and robotic transport can be employed to substantially improve pick-and-pack performance. Other technologies can be used as well. Here's one example of the use of augmented reality in a warehouse:

"DHL recently conducted tests on an augmented reality system at a warehouse in the Netherlands owned by Ricoh, the Japanese imaging and electronics company. Equipped with smart glasses containing software from Ubimax, employees navigated through the warehouse along optimized routes via the glasses' graphics display, enabling them to find the right quantity of the right item much more efficiently, and with reduced training time. Over the three weeks of the test, 10 order pickers succeeded in fulfilling 9,000 separate orders by picking more than 20,000 items. The resulting productivity improvements and reduction in errors increased the overall picking efficiency by 25 percent" (PWC 2016b, p. 22)."

This example highlights a feature of many Supply Chain 4.0 technologies which will be important for understanding their employment effect. The use of new technology and human labor are often complements, rather than substitutes, especially in conditions where e-commerce is substantially increasing demand for certain goods. Rugaber (2018) reports that the online retailer Boxed in Edison, New Jersey opened up an automated warehouse in Union, New Jersey. Demand for goods was such that the firm ended up employing more humans, adding a third shift, as well as more robots. The new jobs are less physically demanding as well. Rather than taking thousands of steps a day loading items onto carts, employees can stand at stations as conveyor belts bring goods to them.[11]

2.5 E-Commerce is ideally, but not uniquely, suited for Supply Chain 4.0

As we have seen, many of the tools of Supply Chain 4.0 can be applied to traditional store-based retailing. The expansion of e-commerce, however, allows additional ways in which new technologies can be implemented. One obvious feature of B2C-commerce is that the process of purchasing involves electronic data entry on the part of the consumer. This enables information to be captured, preferences to be assessed, and strategies to target the consumer to be implemented, such as the ubiquitous pop-ups which now follow one around the Internet after having viewed a product in a given category.

Although most of the popular discussion of e-commerce is on B2C, nearly 90 percent of e-commerce is in fact business-to-business (B2B) (UNCTAD 2017, from which Table 5.1). This means by definition that it consists of links in supply chains – whether transactions between parts suppliers and assemblers, between distribution centers and retailers, or online purchases of services which in many cases support the supply chain. B2B commerce can be implemented either through websites, much like B2C e-commerce, or through electronic data interchange (EDI). EDI is a mature technology[12] through which the computer systems of the buyer and seller are directly connected using a common record format.[13] As an example of the pervasiveness of EDI, the United Kingdom's Office of National Statistics finds that a majority of all e-commerce in the U.K. consisted of B2B e-commerce conducted through EDI, as opposed to over websites that resemble B2C e-commerce (Table 5.2).

TABLE 5.1 **Top 10 economies by total, B2B and B2C e-commerce, 2015, unless otherwise indicated**

		Total		B2B		B2C
	Economy	$ billion	Share in GDP (%)	$ billion	Share in total e-commerce (%)	$ billion
1	United States	7,055	39	6,443	91	612
2	Japan	2,495	60	2,382	96	114
3	China	1,991	18	1,374	69	617
4	Republic of Korea	1,161	84	1,113	96	48
5	Germany (2014)	1,037	27	944	91	93
6	United Kingdom	845	30	645	76	200
7	France (2014)	661	23	588	89	73
8	Canada (2014)	470	26	422	90	48
9	Spain	242	20	217	90	25
10	Australia	216	16	188	87	28
	Total for top 10	**16,174**	**34**	**14,317**	**89**	**1,857**
	World	**25,293**	**-**	**22,389**	**-**	**2,904**

Source: UNCTAD Information Technology Report 2017.

TABLE 5.2 The United Kingdom reported that about 50 percent of e-commerce in 2017 was electronic data interchange B2B

Mode		Sector	Value in 2015 (billion UK £)	Grand Total (%)
All modes		**Total**	**560**	**100**
	of which	B2B	400	71.4
	of which	B2C	160	28.6
Electronic Data Interchange (EDI)		**Total (B2B)***	**281**	**50.2**
Website		**Total**	**279**	**49.8**
	of which	B2B	119	21.3
	of which	B2C	160	28.6

Source: UK Office for National Statistics.

* EDI can be explained as an automated transaction between businesses and therefore EDI sales are classed as business-to-business sales.

Transactions between businesses which take place without EDI involve multiple processes of transmission and re-copying of data. A customer creates an order manually, perhaps using a computer. The order is transmitted by telephone or fax. It is manually keyed into the vendor's computer system. When the order is fulfilled an invoice is created manually (with or without the aid of a computer). The invoice is sent back to the customer, who enters the data on the invoice manually.

Each of these steps in the process is time-consuming. Moreover, each step is a place at which error can be introduced into the system, leading not only to slow order fulfilment but to lack of fulfilment or mis-fulfilment. An EDI system causes an order created electronically by the customer to be instantly duplicated without error in the vendor's computer system, and the invoice to be similarly electronically duplicated in the customer's computer system.

Besides saving time and labor, and reducing errors, EDI enables a large amount of data capture about customer behavior. Thus, data captured in EDI can be the basis for supply chain analytics using either big data or "small data" techniques. One study of manufacturers in the Czech Republic finds that firms using EDI were also more likely to adopt advanced techniques of inventory management, such as consignment stocks, buffer stocks, and safety stocks[14] (Vrbová et al 2016). The same study reports that sectors with above-average use of EDI include auto parts, electronics, engineering industries, plastics, retailing and textiles. These are all sectors associated around the world with well-organized value chains, showing the use of EDI-driven data capture and analysis in value chains.

3. The impact of Supply Chain 4.0 on consumers – customer fulfilment increasingly resembles magic

In a traditional consumer supply chain, the final step is an in-store retail establishment. Consumers frequently experience the frustration of goods being out of stock, either goods that are usually on the shelves but are not there on the day the consumer is in the store, or goods that the consumer would like to buy and knows that they exist, but that the store does not carry. In such cases, the remedies are familiar. Do you have any more in the back room? May I speak to a manager? For a particularly vigorous consumer inquiry, the manager might be prevailed upon to call another store in the chain, or a regional warehouse or distribution center. By this time, the consumer may well have given up and not made the purchase at all, or gone to a competitor.

Applications of IoT are increasingly used to facilitate the management strategies of "customer-managed inventory" (CMI) or "vendor-managed inventory" (VMI). These strategies represent a revolution in supply chain management of comparable importance to the "just-in-time" revolution in manufacturing pioneered at Toyota and other companies in the 1960s. In such models, information is initially provided by a customer, for example by scanning a bar code associated with a purchase, and then transmitted up the supply chain to the warehouse/distribution center.[15] Technologies such as RFID tags then transmit information to the distribution center so that orders can be fulfilled. The information involved is mediated by EDI (see above under e-commerce). Since demand still cannot be fully forecast, models of inventory management such as scan-based trading or consignment distribute the risk between suppliers and retailers by enabling retailers to take physical possession of inventory while suppliers retain ownership, so that the sale between the supplier and retailer does not actually take place until the final consumer checks out at the register. More complex versions of this transaction are possible.

By mediating a series of linkages between retailers, warehouses, manufacturers, and suppliers of inputs to manufacturing, EDI-driven CMI minimizes forecasting errors along the supply chain. As a hypothetical example, a consumer checking out of an AT&T store in California with a newly purchased Samsung smartphone may, by the single act of purchase, trigger a chain of information going all the way back to a company that supplies Samsung with touch screens relatively quickly, with tight linkages between the "supply chain control towers" of Samsung and AT&T.

Future developments in in-store retailing, enabled by IoT technology, will enhance both the customer experience and the ability of stores to pursue advanced management strategies (Gregory, 2015). Using their cell phones, customers may be able to scan barcodes on items to obtain product information or identify other colors or sizes available on the retailer's website. VIP customers may be offered virtual coupons on entering the store. Smart mirrors may allow customers to "try on" different clothing virtually. This experience, which immerses the customer in a retail environment with the aid of both mobile and in-store devices, may be known as the Internet of Me. From the management standpoint, smart price tags can be changed in real time based on demand or other needs, and "smart shelves" in store could detect low inventory, thus providing further support for CMI and VMI strategies. Of course, many of these same principles apply in markets for intermediate goods – B2B markets. In these markets, the ability to use analytics and advanced supply chain management to improve performance is in many ways more advanced than in business-to-consumer (B2C) markets, especially in sectors such as electronics, apparel, and motor vehicles where sophisticated supply chain methods have been in existence for an extended period of time. This is also discussed in the section on e-commerce.

4. The impact of Supply Chain 4.0 on workers

4.1 Physical labor in warehousing and driving substitutes for household time

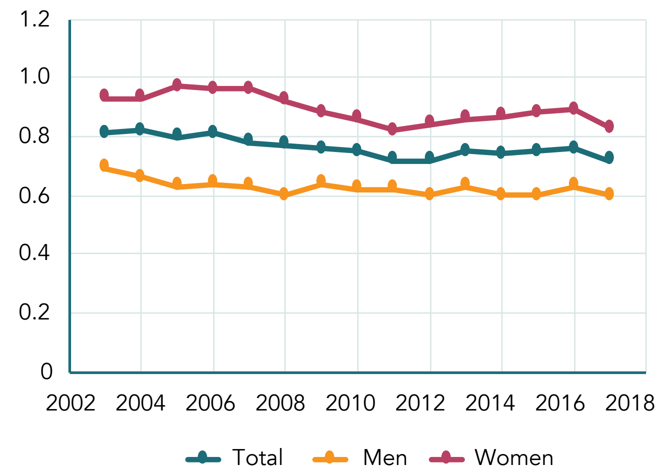
In an important recent contribution, Mandel (2017) demonstrates that U.S. sectors involved in supply chain activities associated with e-commerce have generated a significant amount of employment over the last decade – over twice as much as the reduction in employment in store-based retailing occurring at the same time. Moreover, the jobs involved are reasonably well-paying, and to some extent look like the old factory jobs in manufacturing which became less numerous during the period 1979-2010.

Specifically, Mandel finds that from December 2007 to June 2017, e-commerce jobs in fulfilment centers and e-commerce companies rose by 400,000, substantially exceeding the 140,000 decline in brick-and-mortar retail jobs. On a country by country basis, fulfilment center jobs pay 31 percent more than brick-and-mortar retail jobs in the same area.

Data from the American Time Use Survey (BLS) imply that in 2016, Americans age 15 and over spent 1.2 billion hours *per week* driving to the mall, finding a parking place, wandering around the aisles, checking out, and driving home. The number of hours spent by each such individual shopping per week declined from 4.9 in 2005 to 4.4 in 2012, recovering slightly to 4.5 in 2016. Due to online shopping, in the years between 2006 and 2012 each individual over age 15 spent 6 minutes fewer a day in the purchase of goods and services, which adds up to 11.8 billion leisure hours a year to spend on something else (see Figure 5.7). At the same time, the brick-and-mortar share of retail sales declined from 98 percent to 92 percent.

Thus, e-commerce is a mechanism for translating unpaid household shopping time (which has valuable alternate uses) to paid market time. Instead of consumers spending time shopping, workers in warehouses and on delivery trucks are picking goods off warehouse shelves and bringing them to the consumer's front door. Since time is a scarce resource,

FIGURE 5.7 Hours spent per day shopping in the U.S. (2002-2018)



Source: BLS American Time Use Survey.

particularly in an affluent society, the implications of e-commerce for social welfare are potentially profound. This includes implications for the gender distribution of labor. A reasonable hypothesis is that a further examination of the American Time Use Survey would reveal that the hours spent in shopping activities are disproportionately female, while the employment in supply chain activities are likely to be relatively more those of male mail workers. We leave this hypothesis for future examination.

4.2 Overall trends in supply chain employment

Data

We analyze a group of sectors particularly involved in the distribution of goods, including wholesaling (both traditional and electronic), retailing (both store-based and non-store based), couriers and messengers, and warehousing and storage (Table 5.3). We call the aggregate of these data the "supply chain sectors.' We then use data from the Occupational Employment Statistics (OES) of the U.S. Bureau of Labor Statistics to track sector-level employment as well as employment in individual occupations in each sector. For contrast, we compare the results with trends in manufacturing and in the U.S. economy as a whole.

We focus on the period from 2011-2016. Even though it is a very recent period, it corresponds roughly to the period during which the discussion of "Industry 4.0" (and thus, eventually, "Supply Chain 4.0") crept into the public awareness. This is a shorter period of time than covered in Mandel (2017). Moreover, we have a greater focus on the occupational composition of employment.

TABLE 5.3 Sectors of employment defined as U.S. "supply chain sectors"

	Total supply chain sectors:
423	Merchant Wholesalers (durable & non-durable goods)
425	Wholesale Electronic Markets and Agents and Brokers
441-8 & 451	Specialty Store Retailers
of which	motor vehicles and parts dealers; furniture and home furnishings; electronics and appliance;
	building materials and garden equipment and suppliers; food and beverage;
	health and personal care; gasoline stations; clothing and accessories;
	sporting goods, hobby, book and music
452	General Merchandise Stores
453	Miscellaneous Store Retailers (e.g. dollar stores)
454	Non-store Retailers
of which	Electronic Shopping and Mail Order Houses
493	Warehousing and Storage
481-4	General Transportation
of which	Air, rail, water, and truck transportation
491	Postal Service
492	Couriers and Messengers
	For comparison:
31-33	Total manufacturing
	Total supply chain sectors
	Total U.S. economy

Note: Sectors of employment defined using the Occupational Employment Statistics (OES) data from BLS from 2011-2016.

Supply chain sectors associated with e-commerce experienced rapid employment growth from 2011 to 2016. While employment growth in U.S. supply chain sectors as a whole (8.7 percent) was below that of overall employment (9.2 percent), employment growth was much higher in the subcomponents of warehousing and storage (28.9 percent), non-store retailers (20.3 percent), and couriers and messengers (16.0 percent). Within the subcategory of non-store retailers, employment in the category of electronic shopping and mail-order houses, which approaches most closely the usual conception of e-commerce, grew even more rapidly at 41 percent.[16] The time profile of employment increase shows that while jobs in the "couriers and messengers" sector grew steadily throughout the period, those at non-store retailers experienced an acceleration after 2013, while in warehousing and storage the acceleration kicked in after 2014 (Figure 5.8). In terms of absolute job gains in the supply chain sectors, these were mainly in specialty stores – that is, stores that specialize in one type of merchandise such as food, apparel, electronics, cars, or sporting goods (Figure 5.9). Such stores account for substantially more activity than general merchandise stores. Among the rapidly growing supply chain sectors, the largest job gains have been in warehousing and storage.

Types of employment increasing in supply chain sectors

The dominant category of employment that has expanded in the current supply chain boom is "transportation and material moving operations." Over 2011-2016, these occupations accounted for an increase in employment of over 350,000 in warehouses and courier services (Figures 5.10 and 5.11). These types of jobs involve a combination of physical and mental activity comparable to that of Industry 2.0, but less strenuous because of the effects of mechanization.

Among e-commerce firms proper (electronic shopping and mail-order houses), the greatest absolute growth in employment has been in office and administrative support occupations, with the second largest absolute growth (and largest percentage change growth) being in business and financial operations occupations) (see Figure 5.12). Among specialty stores, employment in many of the back-office occupations has declined, and the gains have come in customer-facing occupations – sales and related occupations, and health care practitioners and technical occupations (see Figure 5.13). The gain in health care workers can be attributed to a single category of specialty stores, pharmacies. Companies such as Walgreens and CVS are increasingly offering vaccinations and other basic health care services hands-on in their retail establishments, which carry many of the same items available in food stores and general merchandise retailers.

5. The impact of Supply Chain 4.0 on GVCs

Supply Chain 4.0 can be seen either as an advanced management practice, or as a cluster of technologies more likely to be adopted as the result of advanced management practices. As shown by recent survey-based research, improvement of management practices – such as may be associated with adoption of Supply Chain 4.0 – is likely to enhance productivity and profitability, lead to higher-quality outputs produced using higher-quality inputs (Bloom, Manova, Sun, Van Reenen and Yu 2018). Supply Chain 4.0 is designed to enhance key management competencies, such as effective target setting, collecting and analyzing data to monitor progress towards these targets, inventory management, coordination of targets/progress across production stages, and worker supervision and incentives.

Supply Chain 4.0 technologies may enable firms to reduce the number of stages in supply chains by reshoring routine labor-intensive activities in developing countries back to the developed countries. These technologies make undertaking some production stages in high-wage countries more profitable by reducing the amount of labor required, thus weakening the incentive for firms to locate in low-wage countries and reducing the importance of low labor costs in determining comparative advantage, providing instead an advantage to integrating multiple stages of production at a single automated location (Dachs *et al.* 2017).

FIGURE 5.8 **Employment growth in U.S. supply chain sectors and overall economy, index, 2011 = 100**

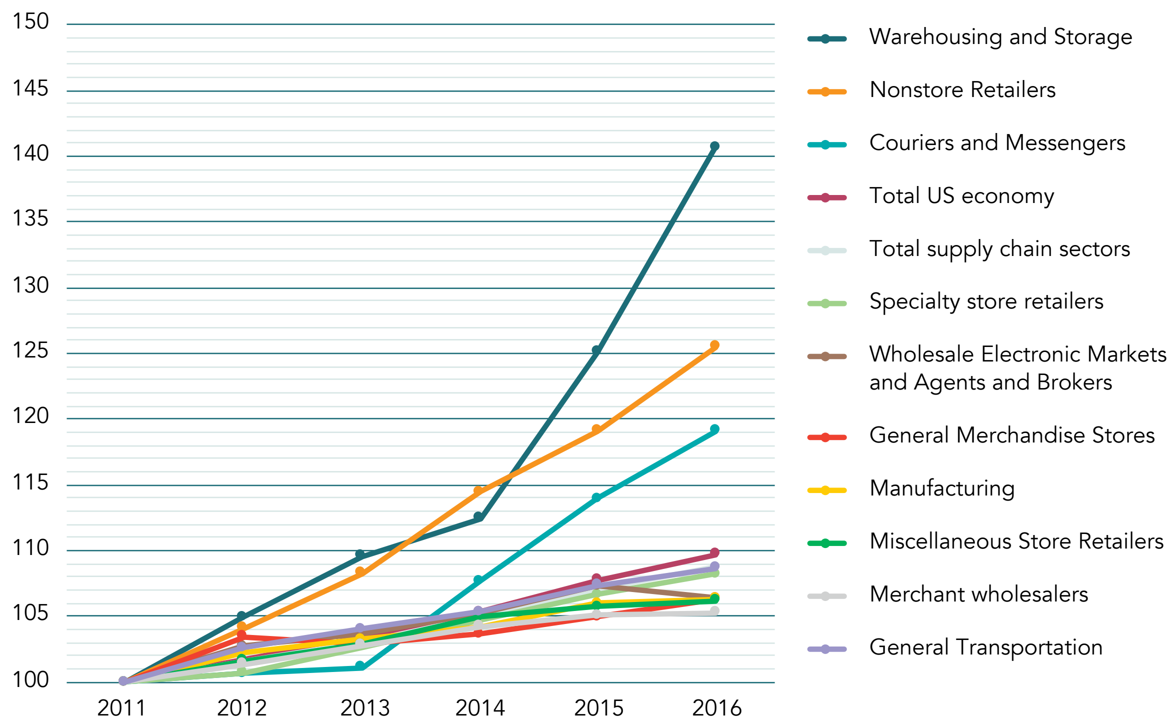


FIGURE 5.9 **Absolute changes in U.S. employment, supply chain sectors, and transportation (2011-2016)**

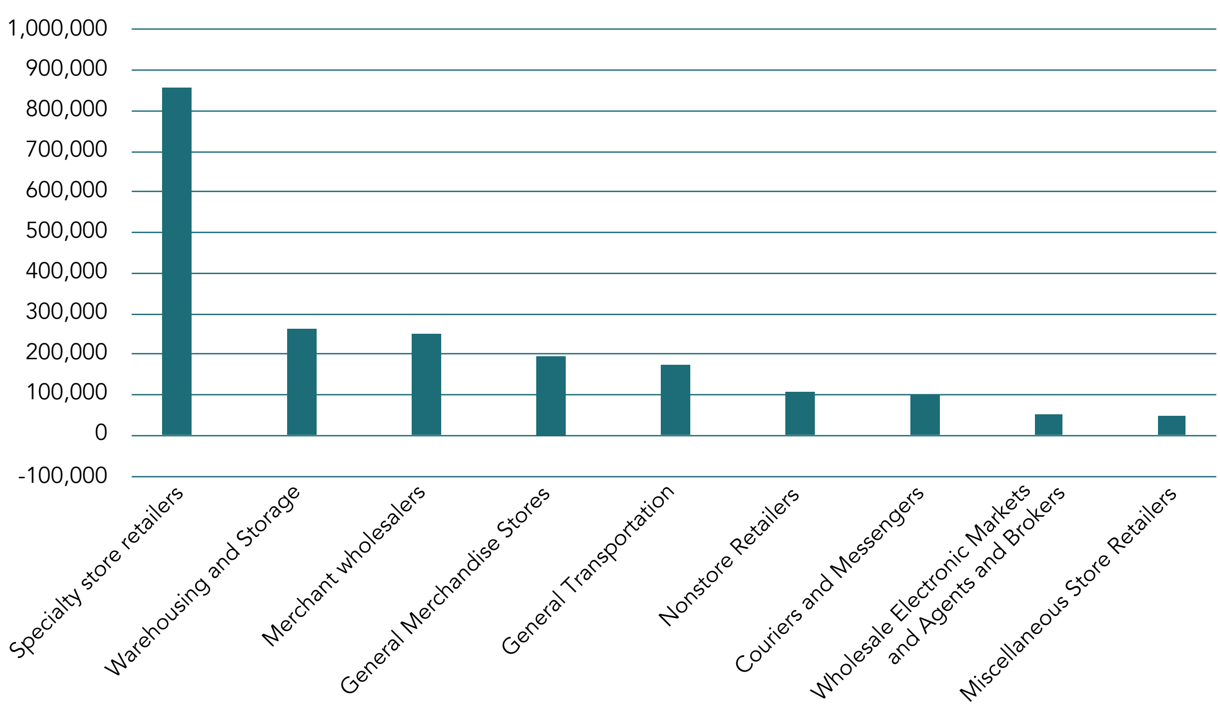


FIGURE 5.10 Warehousing and storage – changes in employment in selected occupations (2011-2016)

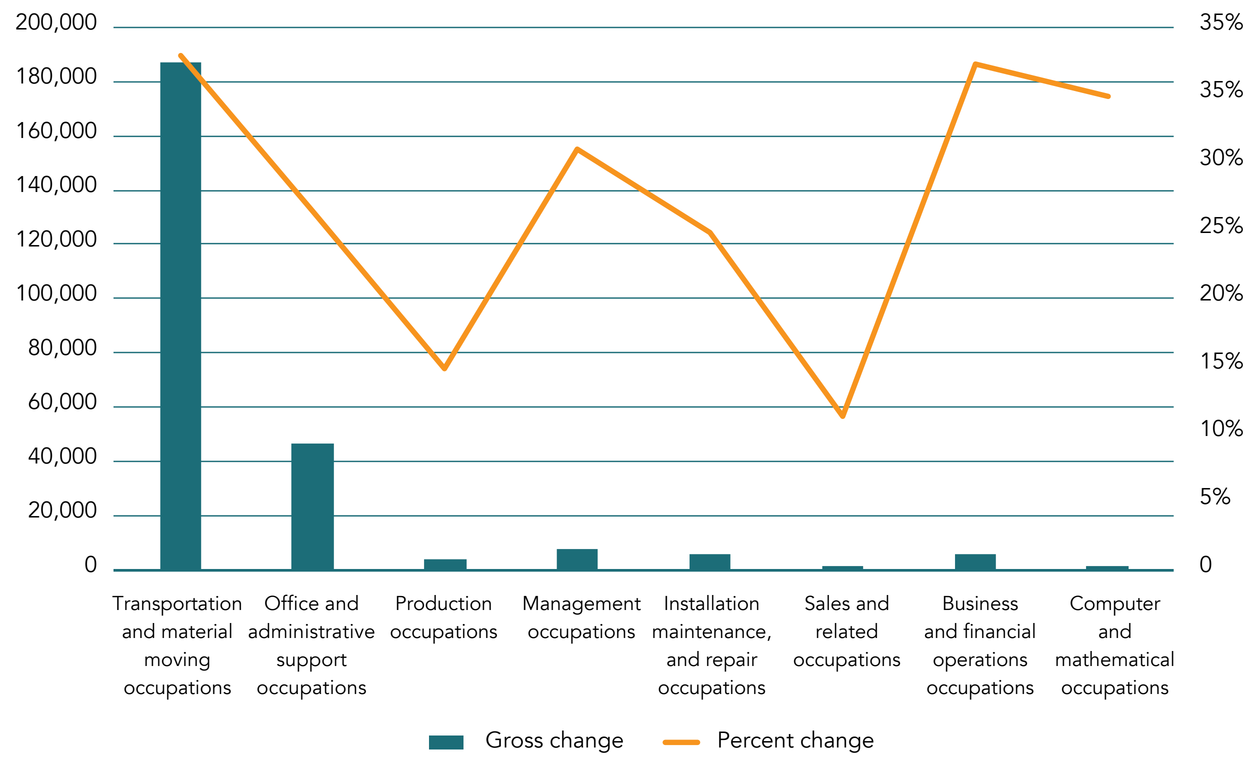


FIGURE 5.11 Couriers and messengers – changes in employment in selected occupations (2011-2016)

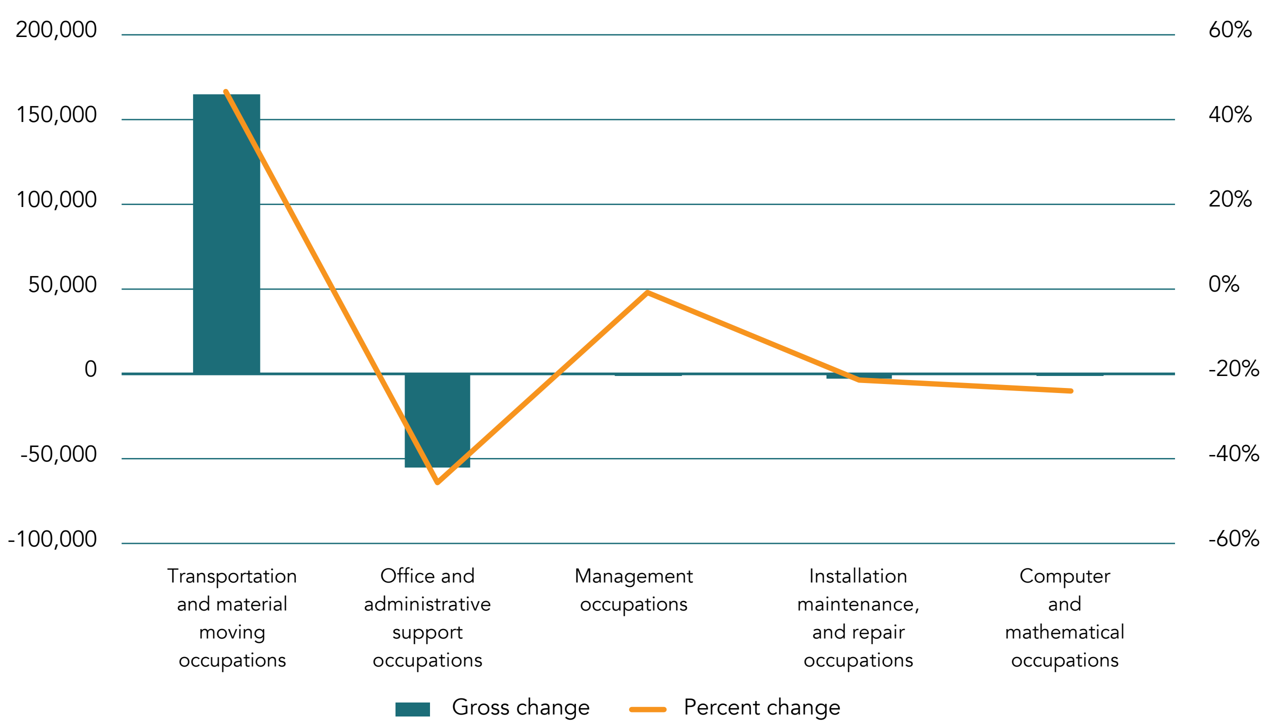


FIGURE 5.12 Electronic shopping and mail order houses – changes in employment in selected occupations (2011-2016)

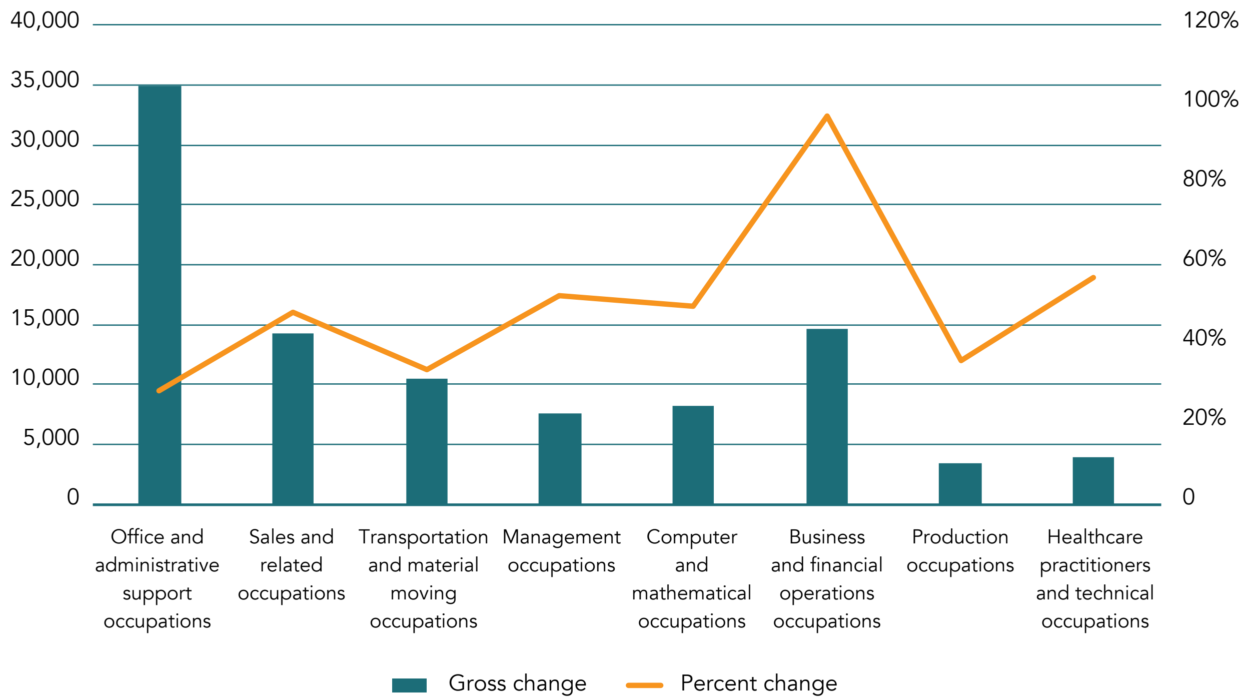
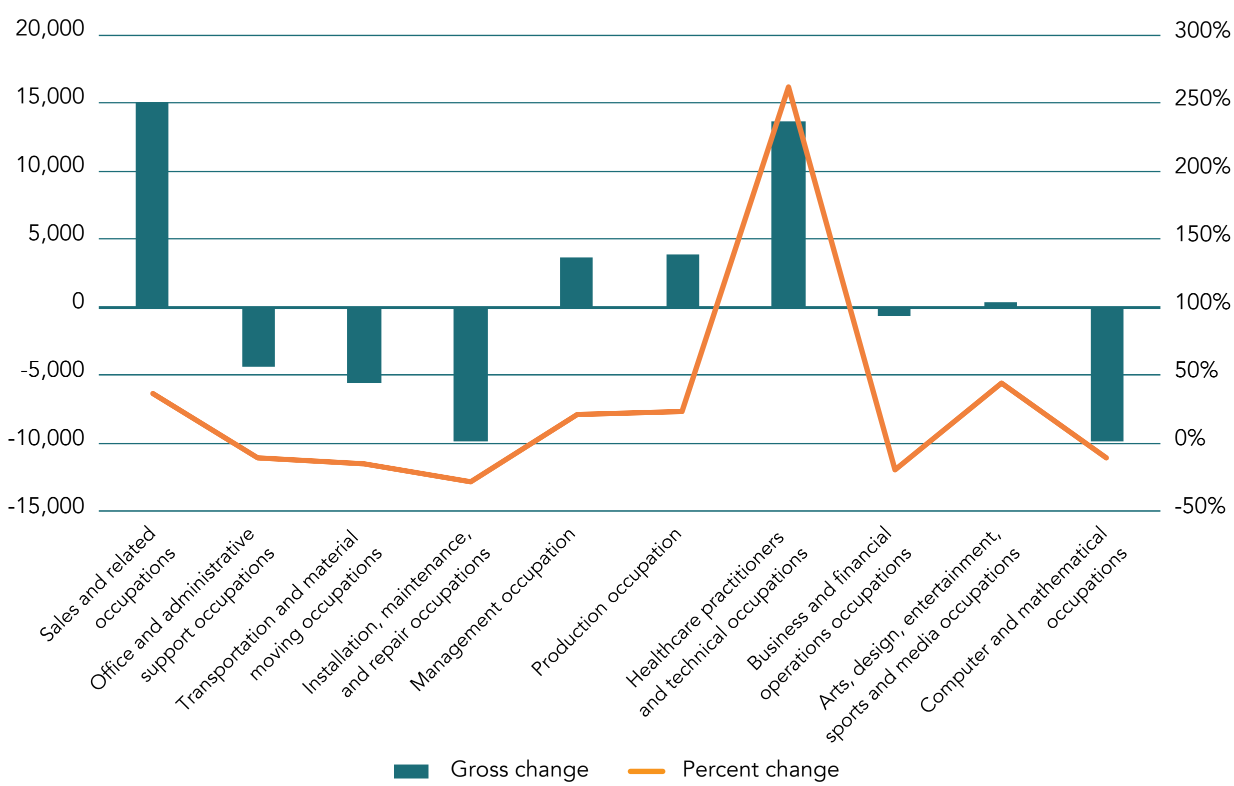


FIGURE 5.13 Specialty stores – changes in employment in selected occupations (2011-2016)



It has been argued that 3-D printing works in this way. According to one estimate it is expected that 3-D printing will disrupt between 4.6 percent and 14.9 percent of global trade flows (Arvis *et al.* 2017). By shortening GVCs, 3-D printing may eliminate the productivity benefits associated with international trade in manufactured goods by reducing the need for unskilled labor-intensive tasks. On the other hand, 3-D printing has actually been associated with increased trade in at least one sector – hearing aids – where the technology has been rapidly adopted (Freund, Mulabdic and Ruta 2018).

The new digital technologies are driving a revolution in the way firms are shaping the organization of their production processes. For example, in 2016, Adidas opened a fully-automated shoe factory using 3-D technology and robotics in Germany. The goal was to individualize its products and react more promptly to consumer needs by bringing manufacturing closer to its clients and speeding up delivery. The number of workers required in this factory is a fraction of the number of people working in emerging economies in the production of the same sportswear (Backer and Flaig 2017). Thus, this form of innovation may slow the growth of GVCs and increase the importance of skills development.

The reshoring of production by high-income countries could reduce demand for the products of manufacturing exporters and stifle the potential entry of newcomers into manufacturing GVCs (Hallward-Driemeier and Nayyar 2017). The higher and more specific investments in advanced production technology are, the greater the possibility to integrate manufacturing operations at one focal plant, favoring reshoring (Dachs *et al.* 2017). A report by Citigroup and the University of Oxford's Oxford Martin School finds that 70 percent of Citi institutional clients surveyed believe that automation will encourage companies to move their manufacturing closer to home, with North America having the most to gain from automation, followed by Europe and Japan. By contrast, the authors estimated that China, Association of Southeast Asian Nations (ASEAN) member countries, and Latin America have the most to lose from automation (Citigroup 2016). Hence, the increased use of labor-saving technologies will change the patterns of comparative advantage of manufacturing in the global market.

On the other hand, developments in the technologies such as IoT, big data and cloud computing can strengthen the current structure of GVCs by reducing the costs of tracking and monitoring the components of production, thus lowering coordination and matching costs. A survey of 152 decision-makers in automotive, aerospace, electronics, and industrial equipment manufacturing companies in Germany, France, and the U.S. finds that the biggest benefit of cloud computing is to reduce the cost of optimizing infrastructure (48.3 percent of respondents), followed closely by efficient collaboration across geographies (47.7 percent) and the ability to respond quickly to business demands (38.4 percent) (the Microsoft Discrete Manufacturing Cloud Computing Survey, Microsoft Corporation 2011).

The degree of adoption and diffusion of Supply Chain 4.0 processes is likely to vary across both firms and countries. As a result, in the medium run it could give rise both to more industrial concentration in sectors where it is important, and to increased income inequality across countries. Countries with higher internet penetration, firms and countries with greater digital entrepreneurial skills, and firms which have mastered previous generations of supply management practices (such as the SCOR model of the 1990s) are likely to have advantages in adopting Supply Chain 4.0 methods.

Conversely, attempts by developing countries to promote entry into new manufacturing sectors, particularly using strategies promoting domestic firms with subsidies, incentives, and special zones, might not take into account whether key players in the supply chain are using the most advanced technologies, and thus be at a competitive disadvantage relative to strategies which successfully attract FDI from firms which have mastered Supply Chain 4.0.

Differences in the rate of diffusion and adoption of Supply Chain 4.0 may not necessarily have negative impacts for poverty alleviation or income growth of people with lower incomes in developing countries. It depends on how the gains from the new management practices are distributed along the supply chain. For example, in some cases the application of advanced supply management practices to an agriculturally-based supply chain originating in developing countries could enable additional steps of food processing in those countries, while in other cases they could lead to increased export of raw materials. In the case of increased export, whether farmers capture any of the gains may depend on whether improved (likely foreign) management of the overall supply chain induces farmers to produce higher-quality produce at higher prices, or to have higher rejection rates. The effects of Supply Chain 4.0 on poverty and shared prosperity are thus likely to be contingent on a variety of local circumstances.

Another potential impact of Supply Chain 4.0 relates to the interactions between firms and governments. Improved supply chain management can lead to increased traceability of goods and financial information. This could make it easier for firms engaged in international trade to satisfy rules of origin by providing a comprehensive audit trail, and it could make it easier for governments to monitor some types of tax evasion.

6. Conclusion

It is dangerous to take a snapshot of recent history, whether of technologies, institutions, or economic trends, and project it very far in the future. Current developments in supply chains appear to be employment-generating, but this could reverse if developments in robotics advance in certain directions. The technology could evolve in entirely unpredictable ways. Or, more pessimistically, its diffusion could stall, limiting the application of Supply Chain 4.0 to already high-income countries and becoming another contributor to global income divergence, which may already be the case with Industry 4.0. Concerns about consumer privacy could easily cause governments to act to forestall some of the developments discussed here. For the present, though, jobs are being created in supply chains, and advances in supply chains are creating benefits for consumers. This can be taken as at least a small cause of optimism.

Notes

1. Or, likely as not, in China, though this chapter does not attempt to document that specifically.
2. Six principles of Industry 4.0 are: 1) Interoperability: the ability for plant equipment (i.e., workpiece carriers, assembly stations and products), humans or smart factories to connect and communicate with each other via the IoT and the Internet of Services; 2) Virtualization: a virtual copy of the smart factory created by linking sensor data (from monitoring physical processes) with virtual plant models and simulation analytics; 3) Decentralization: the ability of cyber-physical systems within smart factories to make decisions on their own; 4) Real-time capability: the capability to collect and analyze data and provide the derived insights immediately; 5) Service orientation: offering of services (of cyber-physical systems, humans or smart factories) via the Internet of Services; and 6) Modularity: flexible adaptation of smart factories to changing requirements by replacing or expanding individual models.
3. Available at: https://www.usatoday.com/story/money/2018/02/19/kfc-chicken-shortage-u-k-restaurants-close-amid-delivery-mishaps/350698002/,February 19, 2018.
4. The term "Industry 4.0" is of German origin. It arises from the German Government's High Tech 2020 strategy, an initiative launched in 2011 and conducted through the Ministry of Education and Research (BMBF) and the Ministry for Economic Affairs and Energy (BMWI) (European Commission 2017). As popularized, Industry 4.0 refers to the most recent in a sequence of "industrial revolutions" in historical time (e.g. Hallward-Driemeyer and Nayyar 2018, 40-41).
5. The definition by analogy to Industry 4.0 corresponds to the most common usage of "Supply Chain 4.0", e.g. Alicke et al. 2016, Asthana 2018. To our knowledge, nobody has attempted to provide historically-based definitions of "Supply Chain 1.0," "Supply Chain 2.0" or "Supply Chain 3.0."
6. A "smart factory" is a highly digitized and connected production facility of the type associated with Industry 4.0. The idea of a "smart factory" is still in its infancy and does not refer to a tightly standardized specification of operations.
7. "Augmented reality" refers to a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. It includes as a subcategory "virtual reality," displays of information of a "3D" or "real" character mediated by such hardware as special headsets or gloves.
8. "Artificial intelligence" (AI) refers to the theory and development of computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. It is closely related to the concept of "machine learning," i.e. computer systems that improve their performance with accumulated experience.
9. "Cloud computing" denotes the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer.
10. Figures 5.5 and 5.6 portray a linear supply chain where goods are moved from one location to another sequentially – a structure often referred to as a "snake" supply chain. "Snakes" are contrasted with "spider" supply chains, in which parts and components are brought from dispersed locations to be assembled at a common location (cf. Hiratsuka 2005). The concept of a supply chain control tower applies equally well to "snake" and "spider" type supply chains. In a more elaborate chain, in which some lead firm orders major assemblies from Tier I suppliers, which in turn order sub-assemblies from Tier II suppliers, and so on, the flow of material may resemble a combination of "spiders" and "snakes". In such a complex supply chain, it might make sense for each Tier I supplier to have its own supply chain control tower, with information being further aggregated at the level of the lead firm.
11. Not every development in robotics is complementary to human labor. The development of prototype robots that can pick goods from shelves could lead to robots that would easily replace some workers. However, the dexterous movements of the human hand and arm have proved difficult to replicate mechanically. This replicates the experience of the first Industrial Revolution, in which there was approximately an 80-year gap between the development of mechanical spinning and the invention of the sewing machine (which still needed dexterous human labor). Gordon (2016) reports that in advanced robotics competitions, robots still have difficulty opening doorknobs.
12. International organizations began developing record formats for EDI as early as the 1960s (UN/CEFACT et al 2017). By the 1980s the use of EDI for firm-to-firm transactions, both nationally and across borders, was widespread.
13. The connection for EDI can either be a direct physical (hardwired) connection, or implemented over the Internet, or, more recently, take the form of a cloud-based solution.
14. According to Vrbová *et al.* (2016) in consignment stock the vendor, instead of the buyer, is in charge of managing the buyer's inventory and triggering replenishment orders; in *buffer stock* the placement takes place at a particular critical stage of supply chain; and in safety stock it is stored in the final stage of the supply chain.
15. This paper will use the older term "warehouse" and the more modern term "distribution center" interchangeably, as synonyms. Increasing use of "distribution center" in place of "warehouse" is associated with the spread of more advanced techniques of supply chain management.
16. Besides e-commerce, "non-store retailers" includes such firms as direct sales (i.e. door-to-door or house parties) and vending machines.

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