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Industry 4.0, Global Value Chains and International Business

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Structured Abstract

Purpose: The paper aims to provide an assessment of how the widespread adoption of new digital technologies (i.e. the internet of things, big data and analytics, robotic systems, and additive manufacturing) might affect the location and organisation of activities within global value chains (GVCs).

Approach: The approach in this paper is to review various sources about the potential adoption and impact of the new digital technologies (commonly known collectively as Industry 4.0), to contrast these technologies with existing technologies, and to consider how the new technologies might lead to new configurations involving suppliers, firms and customers.

Findings: We report that the new digital technologies have considerable potential to disrupt how and where activities are located and organized within GVCs), and who captures the value-added within those chains. We also report that Industry 4.0 is still in its infancy, but that its effects are already having an impact upon the nature of competition and corporate strategies in many industries.

Implications: In particular, we draw attention to the potential cyber-risks and implications for the privacy of individuals, and hence the need for regulation.

Originality/value: This is the first published paper to consider the likely separate and joint impacts of the new digital technologies on the practice and theory of international business.

Keywords: industry 4.0; digital technologies; internet of things; big data; robotics; additive manufacturing; 3-D printing; global value chains; international business

Paper type: Viewpoint

Industry 4.0, Global Value Chains and International Business

What is Industry 4.0?

Industry 4.0[1] is a term reputedly first used to describe a high-technology strategy proposed by the German government, and but now commonly used to refer to the development of "cyber-physical systems (CPS) and dynamic data processes that use massive amounts of data to drive smart machines" (Sirkin *et al*, 2015b). More specifically, Industry 4.0 refers to the emergence and diffusion of a range of new digital industrial technologies (Rüβmann *et al*, 2015), notably embedded sensors so that smart products and devices can communicate and interact with each other (the Internet of Things); the collection and real-time evaluation of data to optimize the costs and quality of production (Big Data and Analytics); robots with greater autonomy and flexibility; and advanced manufacturing techniques, such as additive manufacturing (3-D printing)[2]. Many of these digital technologies have been available for some time, but recent cost reductions and improvements in reliability mean that their deployment for industrial applications is now more commercially viable (Baum and Wee, 2015) though it likely that this deployment may well take 15-20 years to be fully realised. Potentially industry 4.0 may bring about a change from isolated manufacturing activities to automated, optimized and fully-integrated product and data flows within (global) value chains.

The paper proceeds as follows. We first outline the key features of the four new digital technologies, and discuss their likely impacts of their deployment on the location and organisation of activities within global value chains (GVCs). We then consider the implications of the technologies for IB theory and, in particular, for the nature of ownership, location, and internalisation advantages experienced my multinational enterprises (MNEs). We finish by highlighting various policy issues and putting forward some suggestions for future research.

The New Digital Technologies and their Impacts on the Configuration of GVCs

In this section, we briefly outline the essential features of the four digital technologies, and discuss how their (eventual) adoption might disrupt existing configurations of location and control within global value chains.

The Internet of Things (IoT)

An increasing number of physical products are being equipped with sensors that are able to capture and process data, and to then communicate that data to people and other products. Much of the popular attention has been devoted to consumer applications, such as connected household appliances[3]. But the potential for business-to-business applications are potentially more far-reaching, with sensors able to provide real-time data *inter alia* to detect equipment wear-and-tear and thus permit preventative maintenance, to monitor inventory levels and allow better capacity planning, and to assess the usage and functionality of products (Bughin *et al*, 2015a). This will involve a greater integration of data between firms, suppliers and customers, and a reduction in the need for intermediaries (Porter and Heppelmann, 2014). Furthermore, the IoT will bring fundamental changes in the management of geographically-dispersed value chains. Presently, most firms monitor flows of physical products, and also maintain separate flows of information. But, with IoT, products will be assigned unique identifiers, and will be inextricably linked to information about their provenance, use, and destination. There will no longer be a need to coordinate and synchronise product and information flows. This conflation will potentially give rise to substantial benefits in production and distribution efficiency, and particularly so when cross-border flows within global value chains are involved. We might thus expect the advent of the IoT to reduce the transaction costs associated with international production, and to facilitate an ever-deeper international division of labour in the global factory (Buckley and Strange, 2015). This echoes Ronald Coase (1937: 397) who noted 80 years ago that "changes like the telephone and the telegraph which tend to reduce the cost of organising spatially will tend to increase the size of the firm. All changes which improve managerial technique will tend to increase the size of the firm."

But there are also drawbacks. As Bughlin *et al* (2015b: 8-9) note, the "prospect of implementing the Internet of Things should prompt even greater concern about cybersecurity among executives. IoT poses not only the normal risks associated with the increased use of data but also the vastly greater risks of systemic breaches as organizations connect to millions of embedded sensors and communications devices. Each is a potential entry point for malicious hackers, and …. the same interoperability that creates operational efficiency and effectiveness also exposes more of a company's units to cyber-risks."

Big Data and Analytics (BDA)

For many years, firms made business decisions drawing upon data from a limited range of traditional sources such as production records, internal accounts, and market research reports. But data are now generated from a plurality of sources, notably including sensor-generated data from smart products and data from search engines and social media sites (e.g. Google, Facebook, Twitter), and this has provided firms with new sources of potentially valuable information (Davidson *et al*, 2012; Mayer-Schönberger and Cukier, 2013; George *et al*, 2014). This, together with improvements in computing power and lower data storage costs, has led to the growth of big data and analytics. As Davenport *et al* (2012) emphasise, a fundamental feature of BDA is that it is forward-looking, and involves mining existing and new data sources for patterns, events, and opportunities, whereas the traditional role of information technology (IT) had been more backward-looking and concerned with monitoring processes and notifying management of anomalies. McAfee and Brynjolfsson (2012) report that firms that have adopted BDA report consequent improvements in productivity and financial performance.

The potential implications of BDA for international business are both clear and considerable. In particular, firms be able to monitor emerging trends and opportunities in overseas markets without the need to make substantial resource commitments in local marketing affiliates, and they will be able to optimise more effectively their supply, production and distribution activities around the world. But there are two major caveats to corporate success in this brave new world. The first is that the availability of good-quality big data may well be a source of value for firms, but successful firms will require a range of technical and governance capabilities to analyse and operationalise that data so as to realise the potential benefits (Davidson *et al*, 2012; McAfee and Brynjolfsson, 2012; Constantiou and Kallinikos, 2015; Henke *et al*, 2016). The second is that individuals' privacy will be under threat from widespread big data application. "When data becomes priceless, businesses will go an extra mile to procure it. Even today, prying eyes watch every move we make. Facebook knows what we like, Google knows what we browse, and Twitter knows what is on our mind. To top it all, our telecom service providers know where we are, and who we are connecting with. Collectively, it is an incredible amount of information and can be more than what our closest friends or family would know about us." (Shukla, 2015) Some commentators even fear that BDA may provide a threat to democracy (Helbing *et al*, 2015). Some form of (transnational) governance regime will be necessary to regulate this intrusion, and this may well circumscribe the abilities of firms to maximise the commercial potential of BDA. "At the core of the problem is the dilemma thrown up by the very way that the IoTenabled devices operate. Having been designed exclusively to increase productivity and reduce costs, it's very difficult to create a machine that takes more holistic ethical concerns into account. Technology may have an 'ambient IQ', but this is by no means the same as a moral compass." (Maughan, 2014)

Robotics

As Sirkin *et al* (2015a) note, it was in the 1960s that industrial robots first began to appear on industrial assembly lines in the United States, Japan and Europe. But it is only recently that their widespread adoption has become a reality across a range of industries, and this this is due to a confluence of factors. First, the costs of both hardware and software have fallen by more than 20% over the past decade, whilst the performance of robotic systems has improved by about 5% per annum. Costs are projected to fall by a similar amount over the coming decade. As a result, robotic systems are fast becoming a viable economic alternative to human labour in many high-wage economies – though the cost-benefit trade-off varies across industrial sectors. Second, the technical capabilities of many traditional robotic systems have been limited, both in terms of the range of feasible operations and in location. But industrial robots are becoming more versatile and mobile, and able to perform more complex/delicate tasks and to work in less-structured environments. And the most advanced robots are also more intelligent in that they can provide and receive feedback to other parts of the production system though the IoT. Third, robotic systems have in the past involved both substantial capital expenditure and the employment of specialised operatives, and have thus largely been adopted only by large firms. But the improvements in the cost, performance and functionality of many robotic systems have permitted their adoption by many small and medium-sized enterprises.

Over the past few decades, there have been major shifts in the location of many manufacturing activities away from the high labour cost advanced economies of North America, Western Europe and Japan towards the emerging economies in search of lower production costs (Buckley and Strange, 2015). These shifts have been facilitated by a combination of market liberalization and economic restructuring in many countries, international trade and investment liberalization, financial deregulation and the integration of global capital markets, technological advances (notably in IT and transportation), and improved contract enforcement and protection of intellectual property rights in many jurisdictions (Strange and Magnani, 2017). The resultant GVCs involve a physical 'slicing-up' of many manufacturing value chains, with more labour-intensive activities being located in the lower-cost emerging economies. The result has been an international fragmentation of production, with trade in intermediate goods accounting for over 60 percent of world exports - though with marked differences between countries and between products (UNCTAD 2013: 122). The greater availability and lower cost of industrial robotic systems will increasingly impact upon the economics of where to locate manufacturing activities, especially if labour and other production costs continue to rise in many emerging economies and *a fortiori* if there is an increase in protectionist measures around the world (World Trade Organization, 2016). The result may well be the reshoring of many activities to the advanced economies (Albertoni *et al*, 2015), though the aggregate scale of the reshoring phenomenon is thusfar still limited (Oldenski, 2015)[4].

Additive Manufacturing (3-D printing)

Traditional manufacturing processes are subtractive in that parts and components are fabricated using machining techniques which mostly rely on the removal of material by methods such as cutting, drilling, grinding, and sanding. The final products then require assembly of the parts and components. In contrast, 3-D printing[5] is an additive process that creates products by building up successive layers of materials, thus circumventing the need for component assembly (de Jong and de Bruijn, 2013; Janssen *et al*, 2014). A digital model is first generated using computer-aided design (CAD) software, and is then printed as a three-dimensional object in a 3-D printer from raw materials in either liquid or particle form. The printer deposits microscopically thin layers of the raw material, and the product gradually materializes as successive layers are deposited. Many different raw materials may be used as feedstock for 3-D printing, including metals, ceramics, plastics, synthetic resins, porcelain, and glass[6]. Some 3-D printers can combine various materials together in one final product, whilst others can print moving parts.

The adoption of additive manufacturing technologies potentially brings a number of advantages (Janssen *et al*, 2014; Sasson and Johnson, 2016; Laplume *et al*, 2016). First, standard CAD software can be used by anyone (with the necessary skills) anywhere in the world to design products, and then manufacture them using a suitable 3-D printer. Second, every product may be customized to meet the end-user's requirements, as 3-D printing allows for cost-effective production of very small batches – something that is not possible with traditional manufacturing processes. Third, 3-D allows the relatively easy production of complex products, and may well reduce overall production time as several manufacturing/assembly steps are consolidated. Fourth, traditional manufacturing processes generate considerable waste, whilst products often contain surplus material that it is not feasible/economic to remove. In contrast, additive manufacturing generates little or no waste, and design may be optimized so that products use less material and are thus lighter and/or stronger. And, in principle, many additive processes can be reversed, thus dissolving final products into raw material solutions that can be re-used. Finally – and particularly important in an international business context - products designed by CAD software can in principle be manufactured anywhere in the world there is a compatible 3-D printer. Manufacturing does not need to be centralized but may be undertaken close to the end-users, with consequent savings in delivery times and transportation costs, and reduced international flows of intermediate goods and services. Most raw materials are readily available from multiple suppliers and in most countries, hence supply chain risk is minimised. In short, GVCs may be considerably simplified in terms of the number of distinct activities, their geographical dispersion, and the relationships between independent participants.

However, additive manufacturing technologies currently suffer from a number of drawbacks, which limit their use (Janssen *et al*, 2014; Holweg, 2015; Sasson and Johnson, 2016; Laplume *et al*, 2016). First and foremost, current additive technologies are relatively slow and inefficient whilst – unlike subtractive processes - production is not subject to economies of scale. Additive manufacturing processes are thus not currently suitable for mass production as unit costs are substantially higher, and their use has so far been largely confined to prototypes, high-value small-volume components, and out-of-production replacement parts. 3-D printing is thus currently a viable option for more customized manufacturing applications and, as Sasson and Johnson (2016: 86) note, “3D printing provides the conditions where the number of available physical products may increase by several orders of magnitude. Similar to the manner that eBay created a platform for used goods, Amazon created a platform for less commonly purchased books, and Google created a market for less commonly sought information, 3D printing creates a market for less commonly demanded manufactured goods.” They also envisage the creation of 3-D printing supercenters (i.e. specialist facilities that undertake low-volume, customized production) that are co-located with more traditional production facilities. Second, there is a limited, but increasing, range of raw materials that can be used for 3-D printing, and also a limited range of colours and surface finishes. And most printers are limited in terms of the dimension of the end-product, so large products still have to be manufactured by other technologies. Third, 3-D printing cannot yet match the levels of engineering precision achieved by other technologies, and products also suffer from other limitations such as limited strength, lower resistance to heat and moisture, and compromised colour stability.

Implications for International Business Practice

Industry 4.0 is still in its infancy, and the widespread deployment of many of its constituent technologies is still some years away. But its effects are already having an impact upon the nature of competition and corporate strategies in many industries (Porter and Heppelmann, 2014; Rüβmann *et al*, 2015; Lorenz *et al*, 2016; Rose *et al*, 2016). Greenberg *et al*, 2017) report that cross-border data flows are increasing at rates that are almost 50 times those of the last decade, during a time when traditional globalization metrics (trade and FDI flows) are slowing. And, as Kietzemann *et al* (2015: 214) comment in the context of additive manufacturing, "As with most disruptive technologies, it is likely that we will overestimate the potential of 3-D printing in the short term while underestimating it in the long term."

The widespread adoption of the constituent technologies has the potential to transform the location and organization of manufacturing production worldwide (Rüβmann *et al*, 2015)[7], and also to further blur the distinction between what is considered a product and what is considered a service. Greater automation will displace lower-skilled labour, but increase demand for higher-skilled labour (e.g. software specialists, mechatronics engineers, data analysts). Integrated real-time communications through global value chains will reduce the need for work-in-progress inventory. And enhanced machine-to-machine and machine-to-human interaction will allow greater product customization. Distribution will be effected by unmanned logistic drones, at least once the considerable safety issues have been resolved. Labour productivity should rise, and labour costs should fall, in the medium-term, and firms will base their production location decisions less on production costs and more on proximity to customers.

New business models will emerge. Bogers *et al* (2015:225) envisage "a move from centralized to decentralized supply chains, where consumer goods manufacturers can implement a 'hybrid' approach with a focus on localization and accessibility or develop a fully personalized model where the consumer effectively takes over the productive activities of the manufacturer." Customers will become more involved in GVCs, as providers of key information and feedback on products, and even as local manufacturers. Relationships between firms and customers will be redefined in many ways as big data and analytics allow the possibility to test in advance new products and services on clients located anywhere in the world, and to increasingly customise the firm offer to reduce development, launch and adaptation costs. The standardisation versus adaptation decision - long a key issue in international marketing theory and practice - will require a comprehensive re-evaluation in the light of this customisation.

To compound the pressures on existing firms, new players will also emerge. The advent of the digital economy witnessed the arrival of firms like Google and Facebook, which now cater to billions of users. Their innovative business models provide different conceptions of international business and the MNE, and Industry 4.0 will likewise lead to the rise of new organizations which leverage the new digital technologies but are not constrained by a need to adapt pre-existing models, routines and capabilities. The further growth of digital platforms for the distribution of products (e.g. Amazon, Alibaba) should also make it easier for small firms to enter global markets[8].

Finally new national and supranational institutional arrangements will emerge to reflect and regulate the emerging complex reality (Bhattarcharya *et al*, 2016). As Rüβmann *et al* (2015: 12) comment, the "growing interconnectivity of machines, products, parts, and humans will also require new internationals standards that define the interaction of these elements in the digital factory of the future. Efforts to develop these standards are in their infancy but are being driven by traditional standardization bodies and emerging consortia. Germany's Plattform Industrie 4.0 was the first driver, but the US-based Industrial Internet Consortium (IIC) - founded in March 2014 by manufacturing, Internet, IT, and telecommunications companies – has become a prominent alternative. Subsequently, a new body, the Dialogplattform Industrie 4.0, was formed in Germany to counteract the IIC's strong position. Several other standardization organizations have ambitions in the field." New data protection laws and/or stronger industry self-regulation will need to be formulated to safeguard the privacy of individuals, and to put limits on what data can be accessed, stored and transmitted both nationally and across borders (Weber, 2010; Weber, 2013; Rose *et al*, 2015). Who will have legal title over, and who will bear legal responsibility for, products which involve consumer-generated intellectual property (Berthon *et al*, 2015), and how will these issues be handled in cross-border settings? Finally, the inevitable reconfiguration of global value chains, and the changing power relationships between the participants, will lead to ever-greater confusion about where products are made, where value is generated, who benefits, and thus where taxes and customs duties should be levied (Groth *et al*, 2014). Echoing the policy debate (Reich, 1990; Reich, 1991; Tyson, 1991) in the 1990s about who is "us" and who is "them", governmental attitudes towards trade and investment promotion/regulation will need to adapt to the new reality.

Final Comments

What are the implications of Industry 4.0 for MNEs and international business theory? First and foremost, the emergence of new institutional arrangements will clearly impact upon the activities and strategic decisions of MNEs, and this would be a fertile area for future research. Furthermore research might also consider the following questions, grouped according to the familiar framework of the eclectic paradigm (Dunning 1977, 2000) and couched in terms of ownership, location, and internalization (OLI) advantages.

What will constitute important ownership (firm-specific) advantages under Industry 4.0? What value chain activities will MNEs need to control, and what isolating mechanisms will they need to possess (Rumelt, 1984; Rumelt, 1987; Lawson *et al*, 2012) in order for them to capture the rents earned in GVCs? If manufacturing activities are carried out by a combination of publicly-available robotic systems and independent 3-D printing supercenters, then will the ownership of production capacity allow effective value capture, or can such activities be outsourced? Will it become more important for MNEs to control the design and distribution stages of GVCs? But 3-D printing will potentially allow customers to have greater input both in the design of their products, and control over where and when it is manufactured. Or will BDA adoption allow large firms to anticipate market trends and to offer customer benefits that are hard for competitors to imitate? Will formal property rights allocated by the State (e.g. patents, trademarks, licenses) or brand names and/or corporate reputations be effective isolating mechanisms in a world of product customization and dispersed manufacturing?

What will be the nature of location advantages under Industry 4.0? International Business is based on a concept of geography that may be partially challenged in an Industry 4.0 scenario (Gress and Kalafski, 2015). Clearly the greater use of robotic systems will minimize the cost economies to be realized from locating manufacturing activities in low labour cost countries, such as the emerging economies. But will this mean that such activities are reshored to traditional (advanced economy) locations? If so, what will be the impact upon employment opportunities (Frey and Osborne, 2017) given the capital-intensive nature of the manufacturing process? Or will manufacturing activities increasingly be located closer to the final customers? Certainly this would be the logical conclusion from the widespread adoption of 3-D printing. These developments will have significant impacts upon what products are traded, what is exported from where and imported to where, and where jobs are sustained. The spread of additive manufacturing would reduce trade in finished goods, and local availability of the necessary raw materials would also reduce trade in intermediate goods. How will host and home country governments react, and what policies will they enact to promote/restrict trade and FDI?

Finally, what internalization advantages will be critical under Industry 4.0? Are there advantages to being vertically-integrated in the face of the technological changes identified above (Afuah, 2001; Langlois, 2003) and, if so, what should be internalized and what should be externalized? Should knowledge (including big data) be increasingly internalised within MNEs, whilst operations are increasingly externalised? Certainly it appears that the key capabilities that will guide firm performance in the future will be those that address, on the one hand, the need to anticipate and shape future customer demands and, on the other hand, the need to bring about greater efficiencies in the distribution of final goods. These capabilities are inextricably linked to the deployment of BDA and the Internet of Things, and it will be firms that can afford to invest in these nascent digital technologies and employ the associated high-skilled skilled labour that will flourish. This is the future of the multinational enterprise in the coming decades of the 21st Century.

Bibliography

Afuah, A. (2001). 'Dynamic boundaries of the firm: are firms better off being vertically integrated in the face of a technological change?' *Academy of Management Journal*, vol.44, no.6, pp.1211-1228.

Albertoni, F., Elia, S., Fratocchi, L., and Piscitello, L. (2015). 'Returning from offshore: what do we know?' *AIB Insights*, vol.15, no.4, pp.9-12.

Baum, C. and Wee, D. (2015). *Manufacturing's next act*. McKinsey & Company.

Berthon, P., Pitt, L., Kietzmann, J. and McCarthy, I.P. (2015). 'CGIP: managing consumer-generated intellectual property.' *California Management Review*, vol.57, no.4, pp.43-62.

Bhattacharya, A., Bürkner, H-P. and Bijapurkar, A. (2016). *What you need to know about globalization's radical new phase*. Boston Consulting Group.

Bogers, M., Hadar, R. and Bilberg, A. (2016). 'Additive manufacturing for consumer-centric business models: implications for supply chains in consumer goods manufacturing.' *Technological Forecasting* and *Social Change*, vol.102, pp.225-239.

Buckley, P.J. and Strange, R. (2015). 'The governance of the global factory: location and control of world economic activity.' *Academy of Management Perspectives*, vol.29, no.2, pp.237-249.

Bughin, J. Lund, S. and Manyika, J. (2015a). 'Harnessing the power of shifting global flows.' *McKinsey Quarterly*, February, pp.1-13.

Bughin, J., Chui, M. and Manyika, J. (2015b). 'An executive's guide to the internet of things.' *McKinsey Quarterly*, vol.4, pp.92-101.

Christensen, C.M., McDonald, R., Altman, E.J. and Palmer, J. (2017). 'Disruptive innovation: intellectual history and future paths.' Harvard Business School, Working Paper 17-057.

Coase, R. (1937). 'The nature of the firm.' *Economica*, vol.4, no.16, pp.386–405.
Constantiou, I. and Kallinikos, J. (2015). 'New games, new rules: big data and the changing context of strategy.' *Journal of Information Technology*, vol.30, no.1, pp.44-57.
Davenport, T.H., Barth, P. and Bean, R. (2012). 'How big data is different.' *MIT Sloan Management Review*, vol.54, no.1, pp.43–46.
De Jong, J.P.J. and Bruijn, E. (2013).'Innovation lessons from 3D printing.' *MIT Sloan Management Review*, vol.54, no.2, pp.43-52.
Dunning, J.H. (1977). 'Trade, location of economic activity and the MNE: a search for an eclectic approach.' In B. Ohlin, P.O. Hesselborn and P.M. Wijkman (eds), *The international allocation of economic activity*, pp.395-431. London: Macmillan.
Dunning, J.H. (2000). 'The eclectic paradigm as an envelope for economic and business theories of MNE activity.' *International Business Review*, vol.9, no.1, pp.163-190.
Frey, C.B. and Osborne, M.A. (2017). 'The future of employment: how susceptible are jobs to computerisation?' *Technological forecasting and social change*, vol.114, pp.254-280.
George, G., Haas, M.R. and Pentland, A. (2014). 'Big data and management.' *Academy of Management Journal*, vol.57, no.2, pp.321–326.
Greenberg, E., Hirt, M. and Smit, S. (2017). 'The global forces inspiring a new narrative of progress.' *McKinsey Quarterly*, April.
Gress, D.R. and Kalafsky, R.V. (2015). 'Geographies of production in 3D: theoretical and research implications stemming from additive manufacturing.' *Geoforum*, vol.60, pp.43-52.
Groth, O., Esposito, M. and Tse, T. (2014). 'Swarm economics: how 3D manufacturing will change the shape of the global economy.' *European Business Review*, September-October, pp.34-38.
Helbing, D., Frey, B.S., Gigerenzer, G., Hafen, E., Hagner, M., Hofstetter, Y, van den Hoven, J., Zicari, R.V. and Zwitter, A. (2017). 'Will democracy survive big data and artificial intelligence?' *Scientific American*, 25 February. Available at: https://www.scientificamerican.com/article/will-democracy-survive-big-data-and-artificial-intelligence/ (accessed 10 May 2017)
Henke, N., Bughin, J., Chui, M., Manyika, J., Saleh, T., Wiseman, B. and Sethupathy, G. (2016). *The age of analytics: competing in a data-driven world*. McKinsey Global Institute.
Holweg, M. (2015). 'The limits of 3D printing.' *Harvard Business Review: Digital Review Articles*, 23 June, pp.2-4.
Janssen, R., Blankers, I., Moolenburgh, E. and Posthumus, B. (2014). *The impact of 3-D printing on supply chain management*. Delft: TNO Transport and Mobility.
Kietzmann, J., Pitt, L. and Berthon, P. (2015). 'Disruptions, decisions, and destinations: enter the age of 3-D printing and additive manufacturing.' *Business Horizons*, vol.58, no.2, pp.209-215.
Langlois, R. (2003). 'The vanishing hand: the changing dynamics of industrial capitalism.' *Industrial and Corporate Change*, vol.12, no2, pp.351-385.
Laplume, A.O., Petersen, B. and Pearce, J.M. (2016). 'Global value chains from a 3D printing perspective.' *Journal of International Business Studies*, vol.47, no.5, pp.595-609.
Lasi, H., Fettke, P., Kemper, H-G., Feld, T. and Hoffmann, M. (2014). 'Industry 4.0.' *Business & Information Systems Engineering*, vol.2, pp.239-242.
Lawson, B., Samson, D. and Roden, S. (2012). 'Appropriating the value from innovation: inimitability and the effectiveness of isolating mechanisms.' *R & D Management*, vol.42, no.5, pp.420-434.

Lorenz, M., Küpper, D., Rüβmann, M., Heidemann, A. and Bause, A. (2016). *Time to accelerate in the race toward Industry 4.0*. Boston Consulting Group.

Maughan, A. (2014). 'The legal implications of the internet of things.' *The Manufacturer*, 8 July. Available at: http://www.themanufacturer.com/articles/the-legal-implications-of-the-internet-of-things/ (accessed 10 May 2017)

Mayer-Schönberger, V. and Cukier, K. (2013). *Big data: a revolution that will transform how we live, work and think*. Boston and New York: Houghton Mifflin Harcourt.

McAfee, A. and Brynjolfsson, E. (2012). Big data: the management revolution.' *Harvard Business Review*, vol.90, no.10, pp.61–67.

Oldenski, L. (2015). 'Reshoring by US firms: what do the data say?' Peterson Institute for International Economics, Policy Brief PB15-14.

Porter, M.E. and Heppelmann, J.E. (2014). 'How smart, connected products are transforming competition.' *Harvard Business Review*, vol.92, no.11, pp.64-88.

Reich, R.B. (1990). 'Who is us?' *Harvard Business Review*, vol.68, no.1, pp.53-64.

Reich, R.B. (1991). 'Who is them?' *Harvard Business Review*, vol.69, no.2, pp.77-88.

Rose, K., Eldridge, S. and Chapin, L. (2015). *The internet of things: an overview. Understanding the issues and challenges of a more connected world*. The Internet Society (ISOC).

Rose, J., Lukic, V., Milon, T. and Cappuzzo, A. (2016). *Sprinting to value in Industry 4.0*. Boston Consulting Group.

Rüβmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M. (2015). *Industry 4.0: the future of productivity and growth in manufacturing industries*. Boston Consulting Group.

Rumelt, R.P. (1984). 'Towards a strategic theory of the firm.' In R. Lamb (ed), *Competitive strategic management*, pp.566–570. Englewood Cliffs, NJ: Prentice Hall.

Rumelt, R.P. (1987). 'Theory, strategy and entrepreneurship.' In D.J. Teece (ed), *The competitive challenge: strategies for industrial innovation and renewal*, pp.137–158. Cambridge MA: Ballinger.

Sasson, A. and Johnson, J.C. (2016). 'The 3D printing order: variability, supercenters and supply chain configurations.' *International Journal of Physical Distribution and Logistics Management*, vol.46, no.1, pp.82-94.

Shukla, A. (2015). 'The big and small of big data.' Available at: https://medium.com/smart-products/the-big-and-small-of-big-data-2dec0106f5c5 (accessed 10 May 2017)

Sirkin, H.L., Zinser, M. and Rose, J.M. (2015a). *The robotics revolution: the next great leap in manufacturing*. Boston Consulting Group.

Sirkin, H.L., Zinser, M. and Rose, J.M. (2015b). *Why advanced manufacturing will boost productivity*. Boston Consulting Group.

Strange, R. and Magnani, G. (2017). 'Outsourcing, offshoring and the global factory.' In G. Cook and F. McDonald (eds), *The Routledge companion on international business and economic geography*. London: Routledge.

The Economist (2015). 'New materials of manufacturing.' *Technology Quarterly* (12 May). Available at: http://www.economist.com/technology-quarterly/2015-12-05/new-materials-for-manufacturing (accessed 10 May 2017)

Tyson, L. (1991). 'They are not us: why American ownership still matters.' *American Prospect*, Winter, pp.37-49.

UNCTAD (2013). *World investment report 2013. Global value chains: investment and trade for development*. New York and Geneva: UNCTAD.

Weber, R.H. (2010). 'Internet of things: new security and policy challenges.' *Computer Law* and *Security Review*, vol.26, no.1, pp.23-30.

Weber, R.H. (2013). 'Internet of things: governance quo vadis?' *Computer Law* and *Security Review*, vol.29, no.4, pp.341-347.
World Trade Organization (2016). *Report on G20 trade measures*. Geneva: WTO.

Notes

[1] Industry 4.0 is considered to be the fourth industrial revolution, following mechanization (the first revolution) in the nineteenth century, the intensive use of electrical energy for mass production (the second revolution) in the early part of the twentieth century, and widespread digitalization (the third revolution) in the 1970s. (Lasi *et al*, 2014)

[2] Rüßmann *et al* (2015) list nine foundational technologies (i.e. big data & analytics; autonomous robots; simulation; horizontal and vertical system integration; the internet of things; cybersecurity; the cloud; additive manufacturing; and augmented reality) that are the building blocks of Industry 4.0, but we concentrate here on just these four technologies because they are likely to have the most influence of firms' international business activities.

[3] For instance, L'Oreal unveiled a smart hairbrush at the 2017 Consumer Electronics show in Las Vegas. The brush has sensors that detect hair quality and breakage, and can then communicate this data to an app and recommend treatments. See the report at http://www.bbc.co.uk/news/technology-38503932 (accessed 10 May 2017)

[4] See also the January 2013 Special Report on 'Outsourcing and offshoring' in *The Economist* (2013).

[5] Additive manufacturing is the official term, but the technology is often referred to as 3-D printing and also as direct digital manufacturing (DDM).

[6] See also the May 2015 Technology Quarterly on 'New materials in manufacturing' in *The Economist* (2015).

[7] See also the literature on disruptive innovation (e.g. Christensen *et al*, 2017).

[8] In this context, see the 2016 proposal by the Alibaba CEO (Jack Ma) for an electronic world trade platform (e-WTP), free of taxes and customs duties, for SMEs. See http://fortune.com/2016/08/22/alibabas-jack-ma-cheerleads-for-totally-free-trade/ (accessed 10 May 2017)