Chapter 5
Industry 4.0 in 'factory economies'

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1. Introduction

Although the disruptive technologies jointly referred to as 'Industry 4.0' (Brettel *et al.* 2014; Hermann *et al.* 2015; Kagermann *et al.* 2013; Váncza *et al.* 2011) have been nearly universally hailed[1] as being set to improve the competitiveness of the manufacturing sector – also in high-wage countries –, scholars are far from unanimous in their assessment of their impact on selected economic subsystems such as the labour market, or on the geographical configuration of value-adding activities. Will these technologies lead to the reshoring of manufacturing and the related advanced support activities, erasing the results of FDI-driven modernisation in the host economies?

As for the former issue, some scholars have discussed the broad implications of the digital economy, looking for example at whether proliferating new forms of employment can be expected to *call the social model of paid employment into question* (Valenduc and Vendramin 2016), or whether, through causing massive job losses, new technologies will jeopardise overall welfare (Sachs *et al.* 2015). In a more definitive approach, several papers have quantified the number of jobs set to be eliminated by Industry 4.0 technologies (e.g. Arntz *et al.* 2016; Bonin *et al.* 2015; Frey and Osborne 2013; WEF 2015), discussing the implications of these developments on wages, the labour income share in national income and inequality (reviewed by Acemoglu and Restrepo 2016). The results of these calculations have been debated by other scholars, claiming that the new technologies will not eliminate jobs in the magnitude posited. By taking over the dullest and the most difficult routine activities, new technologies will in their view lead to a major adjustment in labour supply, eliminating certain activities while at the same time increasing demand for new, complex skills and thus enhancing the creation of 'good jobs' (Acemoglu and Restrepo 2016; Autor 2015; Chui *et al.* 2015; Porter and Heppelmann 2014).

The second issue, the geographical reconfiguration of production activities triggered by the disruptive impact of new manufacturing technologies on global value chains, has raised similar controversies. Whether or not the new manufacturing technologies will bring about major changes in global supply chains, for example prompting the massive reshoring of previously offshored production activities (surveyed by Oldenski 2015) remains to be substantiated by empirical evidence. The opposite is just as conceivable, with the co-location synergies that characterise modern production systems leading to further relocations (this time, the relocation of advanced activities such as R&D)

1. Notable exceptions include Benzell *et al.* 2015; Brynjolfsson and McAfee 2014; Sachs *et al.* 2015.

to offshore, low-cost MNC manufacturing subsidiaries (Tassey 2014), or with certain Industry 4.0 technologies triggering a further decentralisation of manufacturing (Gress and Kalafsky 2015).

This paper is intended to contribute to these strands of the literature from the perspective of FDI-hosting, intermediate-level 'factory economies'.

Central and Eastern European (CEE) countries, and more specifically Hungary, are used as examples of this country group. Following the shift from command to market economies in the CEE countries, their economic actors have become successfully integrated in European and global value chains (GVC), mainly as subsidiaries of multinational companies. CEE economies can thus be classed as 'factory economies' under the Baldwin and Lopez-Gonzalez (2015) categorisation[2], even if local economic actors have achieved substantial product, process and functional upgrading.

Investigating the development perspectives of CEE manufacturing actors in an Industry 4.0 era is intriguing, since this country group represents an intermediate case. On the one hand, it is relatively more developed than peripheral low-cost locations, while on the other it hosts manufacturing subsidiaries that have undergone substantial upgrading in multiple respects.

Our point of departure is that the contradictions in the above-detailed assumptions can be reconciled through broadening the focus of investigation to include factory economies. Indeed, the impact of Industry 4.0 technologies will be a function of an economy's GVC specialisation[3] and how quickly it adjusts to new skill requirements. When examined from a GVC perspective, optimistic and pessimistic scenarios may occur in parallel, with benefits accruing to advanced economies (optimistic scenario), and costs (the adverse effects of the new technologies) accruing in peripheral 'factory' or dependent market economies (Farkas 2011; Nölke and Vliegenthart 2009) unable to adapt to today's high-speed business environment.

The issue at stake is whether the new technologies will annul local subsidiaries' past upgrading achievements, with the relatively advanced activities located in these countries, partly in recognition of demonstrated local competences, being reshored.

2. According to Baldwin and Lopez-Gonzalez (2015), in international production networks there are *headquarter economies* that 'arrange the production networks' and *factory economies* that 'provide the labour' (p. 1696). Scrutinising economies' trade patterns, the cited authors found that factory economies tend to be heavily reliant on the closest high-technology manufacturing economy – the US, Germany and Japan – whereas the sourcing and sales partners of headquarter economies are diversified.

3. For example, according to data published in the Economist (2016), half of the world's full-time call centre jobs are located in two countries: the Philippines (26%) and India (24%). As most of these activities will be subject to the automation of knowledge work – at least of routine cognitive activities (Manyika *et al.* 2013), the economic indicators (output, export, employment) of these countries will be hit above average by the new technologies. In a similar vein, countries specialising in low-skill repetitive manufacturing activities will also face dramatic job losses: for example, in May, 2016 Foxconn fired 60,000 workers in China following the automation of their activities (Millward 2016).

This issue will be discussed conceptually, drawing on the features of Industry 4.0 technologies (section 3). In a multidisciplinary approach, technological and engineering literature is combined with business and management literature. We summarise the specific attributes of selected Industry 4.0 technologies, predicting their impact on the location patterns of manufacturing activities – from the particular perspective of intermediate-level factory economies. Manufacturing activities are considered in a broad sense (Bernard *et al.* 2016) including all related business support activities, such as process development and production scheduling; capacity planning; engineering support for assembly line reconfigurations; testing; order processing; accounting, etc.

This conceptual analysis will be contrasted with interview findings about the adoption of and first experiences with Industry 4.0 technologies in MNC manufacturing subsidiaries in Hungary (section 4). These sections will be preceded by a short summary of the literature related to our investigations (section 2). The final section provides some concluding remarks and policy recommendations (section 5).

2. Definitions and related literature

In a broad sense, Industry 4.0 refers to a bundle of technologies[4] recently adopted in manufacturing and its related support activities (often referred to as advanced manufacturing – Tassey 2014). More narrowly, Industry 4.0 refers to the implementation of cyber-physical systems, resulting in the digitalisation of production (Kagermann *et al.* 2013; Monostori 2015). The flipside of the coin is the integration of new technologies in the products themselves: smart connected products, such as autonomous cars, smart apparel, smart consumer electronics products and smart buildings are themselves cyber-physical systems.

New technologies have dramatically improved adopting firms' operational parameters, such as efficiency, productivity, transparency, costs and flexibility. Moreover, they have altered industry boundaries, generating new business models (changing the way value is created and captured), and transforming corporate strategies (Porter and Heppelmann 2014; 2015).

Among the multiplicity of related strands in the literature (e.g. the expected benefits and challenges of the digital transformation; the speed and scope at which technology is diffused and the factors impacting its adoption; technical change and industry dynamics; the tertiarization of manufacturing and the interdependence of manufacturing and business services; skills and the labour market; global value chains and upgrading) closest to our investigation are papers concerned with the evolution of MNC subsidiaries and with the locational dynamics of value-adding activities along GVCs. These two strands are reviewed in brief below.

4. Examples of new technologies include cyber-physical production systems and the Internet of Things; big data; artificial intelligence and machine learning; cloud computing; 3D-printing (additive manufacturing); industrial robots, and optical 3D measurement (Manyika *et al.* 2013; Monostori 2015).

Birkinshaw (1996) and Birkinshaw and Hood (1998) are among the classical references on the evolution of subsidiaries. They posit that, over time, subsidiaries systematically accumulate resources and specialised capabilities, possibly resulting in their mandates being enhanced. This evolution is driven by increased headquarter (HQ) expectations and assignments and by the related transfer of additional resources (moderated by the capability of subsidiaries to absorb them), and/or by a subsidiary's proactive behaviour and initiative-taking. The development of unique, subsidiary-specific capabilities (Rugman and Verbeke 2001) allows a subsidiary to switch from being a peripheral implementer to a strategic contributor (Bartlett and Ghoshal 1986), or even to a centre of excellence within an MNC's network (Frost *et al.* 2002). Nevertheless, a subsidiary's evolution is no one-way street, as argued by Dörrenbächer and Gammelgaard (2010): its mandate can also be lost, driven by technological or host market changes, developments in the overall business environment, or by other strategic considerations of the parent company.

As for the geographical configuration and the dynamic reconfiguration of value-adding activities, there seems to be a consensus in the literature (e.g. Contractor *et al.* 2010; Koza *et al.* 2011; Linares-Navarro *et al.* 2014) that increasingly fine-sliced activities are *assembled* in GVCs. The term 'assembly' is used here in Koza *et al.*'s (2011) conceptualisation of *strategic assembly* (rather than product assembly), defined as a process consisting of (a) the identification of the necessary resources; (b) the design of the value chain structure and access to resources; and (c) the management and coordination of network relationships that include both equity and non-equity relations.[5]

A further common finding is that the attributes and composition of value chain activities keep changing, driven either by technological and business model innovations (Cano-Kollman *et al.* 2016) or by HQ efforts to adapt the organisational structure to changes in the external business environment (Chandler 1962; Szalavetz 2016a).

Locational choices are determined by matching the nature of the given activity with the tangible and intangible resource endowments of the selected locations. Both aspects need to be analysed in a detailed manner, taking account of phenomena where high-cost locations are selected or retained to host certain manufacturing activities (Jensen and Pedersen 2011). Moreover, location-based competitive advantages are not static, as companies and locations co-evolve (see the review of the related literature in Cano-Kollmann *et al.* 2016).

This paper attempts to bring these two reviewed strands of literature together, investigating the impact of Industry 4.0 technologies on FDI-driven factory economies that had already achieved substantial upgrading before the advent of these technologies. We argue that, in line with the evolutionary view of economic development (Nelson and

5. The business units where the individual value-adding activities take place are not necessarily in the ownership of the value chain orchestrator. As stated by Koza *et al.* (2011): ownership of resources - property rights, assets and operational capabilities - is not necessary for competitive advantage. Ownership may even limit firms' flexibility: their capability to adapt to changes in the business environment.

Winter 1982), technological change induces *selection*, *retention* and *reconfiguration* mechanisms – also within global value chains. In our case, the new manufacturing technologies prompt GVC orchestrators to make strategic locational decisions: whether they (a) keep their existing manufacturing facilities and upgrade them through installing Industry 4.0 technologies (retention); (b) consolidate and concentrate manufacturing activities in a (couple of) specific location(s) (selection); or (c) reshore part of the activities, and at the same time establish new facilities, and/or outsource certain tasks (reconfiguration).

Scenario building, from the perspective of CEE factory economies, is coupled with uncertainties for two reasons. First, there are non-negligible differences between individual CEE economies in terms of their progress towards implementing Industry 4.0 technologies. According to Roland Berger (2014), although no CEE economy can be regarded as a frontrunner in terms of preparedness for the 'Industry 4.0 era', (measured by indicators such as production process sophistication, degree of automation, workforce readiness, innovation intensity and Internet sophistication), some (the so-called 'traditionalist' cluster) are better prepared than others (the so-called 'hesitators').[6] New investment inflows and selection mechanisms may, however, change the Roland Berger ranking of these countries quite rapidly. According to empirical evidence (Roland Berger 2014; Szalavetz 2016b), new foreign-owned manufacturing facilities, established in the mid-2010s, are already highly automated,[7] characterised by state-of-the-art cyber-physical production systems. Accordingly, Industry 4.0 readiness in these countries will significantly depend on the outcome of foreign investors' future location decisions.[8]

Second, it must be borne in mind that Industry 4.0 technologies are heterogeneous. The impact of individual technologies differs across industries. Even within individual value chains, different Industry 4.0 technologies may trigger different geographical reconfiguration mechanisms. This paper is thus limited to discussing certain possible developments associated with selected Industry 4.0 technologies from the perspective of MNC manufacturing subsidiaries in Hungary in the automotive and electronics sectors.

6. Czechia, Hungary, Slovakia, Slovenia and Lithuania belong to the cluster of 'traditionalists', with Czechia featuring the relatively highest performance. Estonia, Poland, Croatia and Bulgaria are referred to as 'hesitators'. Another factor suggesting differences in preparedness is the fact that Czechia is the only CEE economy to have adopted a formal National Industry 4.0 Initiative (in 2016) (https://www.mpo.cz/assets/dokumenty/53723/64494/659339/priloha001.pdf). Hungary is preparing its own national Industry 4.0 strategy, to be completed in 2017. Slovakia is preparing industry-level action plans, envisaging 'smart industry'.

7. According to the International Federation of Robotics, Slovakia was among the top ten countries in terms of the number of multipurpose industrial robots per 10,000 employees in the automotive industry (920) in 2015. (Source: www.ifr.org)

8. Although process sophistication and the degree of automation are the two most spectacular constituents of Industry 4.0 readiness, other constituents less dependent on foreign investment in cyber-physical solutions are equally if not more important determinants of future shifts in CEE rankings. Estonia for example, boasts good results in terms of Internet sophistication due to its e-Estonia programme.

3. Industry 4.0 technologies and the geographical reconfiguration of value chains – Impact on MNC manufacturing subsidiaries

One of the salient technological novelties of the Industry 4.0 era is additive manufacturing, also referred to as 3D printing.[9] As the characteristics, benefits and disruptive implications of this technology on international business have already been extensively discussed (e.g. Berman 2012; Ford 2014; Garrett 2014; Petrick and Simpson 2013), we focus here only on a couple of thought-provoking specifics – from a factory economy perspective.

Although additive manufacturing is expected to fundamentally reorganise not only the way products are manufactured but also manufacturing location patterns, its diffusion is projected to be limited to particular product families. The main obstacles to intensive diffusion[10] are the higher costs and the lower production throughput of 3D printing compared to conventional manufacturing technologies. Hence, even in the medium term, it is projected to be used mostly for manufacturing customised products with a complex design in small quantities (Ford 2014), i.e. precisely the area where factory economies of an intermediate wage level, e.g. CEE countries, have comparative advantages (Artner 2005), as FDI inflows into CEE manufacturing have enhanced specialisation in relatively skill-intensive manufacturing (Damijan *et al.* 2015; Dulleck *et al.* 2005; Pavlínek *et al.* 2009).

It is fair to assume that the comparative advantages of the CEE region as a production location may vanish (at least in these specific products and industries) for the following reasons. 3D printing technology makes it much easier to switch a production location, making it much more dependent on the size and evolution of local market demand, rather than on local labour skills and costs (Berman 2012; Oettmeier and Hofmann 2016). Production will move closer to customers, meaning in general that manufacturing activities using 3D printing instead of conventional production methods (e.g. in certain machinery or automotive component industries) may easily be relocated closer to final or intermediate customers[11] – away from the current medium-wage level countries.

Another often-mentioned benefit of 3D printing is that it eliminates tooling, an expensive and time-consuming step of any new product launch: (e.g. Rosochowski and Matuszak 2000).[12] Moreover, in hybrid processes, 3D printing can be applied to prepare

9. Ford (2014: 2) clarifies the term 3D printing as follows. "Unlike traditional manufacturing processes involving subtraction (e.g., cutting and shearing) and forming (e.g., stamping, bending, and moulding), additive manufacturing joins materials together to build products" by depositing successive layers of polymers, ceramics or metals. The creation of physical products relies on digital models and is computer-controlled, hence it is also referred to as direct digital manufacturing.
10. Intensive diffusion refers here to the range of products manufactured using 3D printing (while extensive diffusion refers to the variety of geographical locations where 3D printing technology is applied). It is argued that, in contrast to rapid extensive diffusion, intensive diffusion will depend on the further development of the technology.
11. By intermediate customers we refer to the production locations where the components and subsystems are assembled into a final product.
12. Note that 3D printing was originally applied solely in rapid prototyping, accelerating product development through eliminating the procedure of designing and manufacturing prototype tools. This attribute of additive manufacturing is reflected by the third synonymous term used: direct digital manufacturing.

the tools themselves, which, once 'printed', can be used in conventional manufacturing processes (Holmström *et al.* 2016; Oettmeier and Hofmann 2016). Again, tooling is a GVC task where CEE actors have comparative advantages. Corporate interviews (e.g. Sass and Szalavetz 2013; 2014) indicate that functional upgrading in manufacturing subsidiaries was manifested, among others, in their taking responsibility for tooling – over and above their core production activities. It remains to be seen whether 3D technology triggers a reshoring of tool design to advanced economies.

A further IT-enabled industrial solution of the Industry 4.0 era is virtual reality-powered product and process development, and the virtual provision of engineering support to various manufacturing-related processes in distributed industrial locations.

Factory economies will be confronted with a thought-provoking implication of this evolution in ways of connecting, knowledge-sharing and collaborating.[13] Several scholars subscribe to the argument that the geographical separation of the tasks making up a value chain is not without limits. Keeping tasks together produces economies of scope (e.g. Lanz *et al.* 2011; Larsen *et al.* 2011). Ketokivi and Ali-Yrkkö (2009: 35) argue that 'as the knowledge intensity of an economic activity increases, the unbundling of several functional activities may no longer be possible: R&D, innovation, design, and branding may be activities that are intimately related with the manufacture of physical products.' Tassey (2014) maintains that certain manufacturing-related advanced support activities display non-negligible co-location synergies. For example, in the case of development activities related to launching a new product where technical knowledge is not yet standardised and requires continuous adjustment, person-to-person interactions are critical, since tacit knowledge is transferred. Tassey argues that in the Industry 4.0 era characterised by technological transition in multiple fields of the manufacturing process, co-location synergies will make it easier for manufacturing locations to take responsibility for and develop critical competences in advanced support activities, ultimately resulting in advanced economies losing their competitiveness.

However, the cited authors take no account of advanced virtual-reality and augmented-reality technologies that allow the geographical separation of tasks to be maintained and for process planning and process engineering support to be remotely provided to manufacturing facilities: bad news for manufacturing locations wishing to move up the value chain!

From the perspective of intermediate-development-level factory economies, the implications of some other Industry 4.0 technological solutions may represent a threat

13. Advanced visualisation solutions (e.g. the virtual representation of robots, machine tools, work pieces etc.) and advanced interaction (interactive real-time 3D simulation) tools allow production systems or parts thereof to be tested before any actual deployment or installation. They make it possible to remotely evaluate and resolve the problems that emerge in the context of industrial processes (Galambos *et al.* 2015). Concurrent (simultaneous) engineering (reliance on virtual reality) has been an established collaboration method since the 2000s, and the related enabling technologies (visualisation, object manipulation, interaction) have been incrementally developed ever since. Virtual reality technologies enable experts from various areas (designers, manufacturing planners, process engineers, marketing and procurement specialists, management, etc.) and in distributed physical locations to collaborate in joint product (or process) development projects. Conversely, augmented reality techniques enhance users' (e.g. assembly operators') perception and understanding of the surrounding world and are used in system maintenance and assembly operations (Ong and Nee 2013).

not only to future upgrading opportunities (in the field of manufacturing-related process development), but may also jeopardise prior upgrading achievements. Most of the smart computing solutions embedded in cyber-physical production systems digitalise activities – and thus, perform them themselves – that used to be classified as upgraded actors' knowledge-intensive assignments. Examples of knowledge-intensive, relatively high-value-adding activities, mentioned during the author's prior interviews (Sass and Szalavetz 2013; Szalavetz 2015) were production line design and factory planning, process configuration, production planning and scheduling, investigation of the machinability of new product designs, process development, e.g. reduced changeover time, reduced throughput time. Augmented reality-powered digital factory applications (Pentenrieder *et al.* 2007) are expected to redefine the tasks of local engineers engaged in line/work cell layout and factory planning. Advanced computing solutions, such as (a) big data–enabled predictive maintenance (Lee *et al.* 2013); (b) modelling and simulation-based smart algorithms for production planning and scheduling, and capacity control, etc. (e.g. Gyulai *et al.* 2015); (c) modelling and simulation-based smart algorithms for optimising process and improving capacity utilisation, throughput and overall effectiveness (e.g. Bard *et al.* 2015), can be expected to take over production planning, scheduling and process development tasks, currently performed by local engineers. At the very least, they will redefine task portfolios of local engineers and the associated skill requirements. In summary, advanced computing solutions may jeopardise local manufacturing subsidiaries' past functional upgrading results.

Furthermore, artificial intelligence and deep learning solutions will automate selected medium-knowledge-intensive support activities (routine cognitive tasks) such as accounting, order processing, payroll management, operational procurement (Lacity and Wilcocks 2015), jeopardising CEE actors' functional upgrading achievements, manifested in the location of shared services centres – near MNC manufacturing subsidiaries (cf. Sass and Fifekova 2011). With the automation of these tasks, a large number of jobs may disappear.[14]

Conversely, selected features of Industry 4.0 technologies represent upgrading opportunities for factory economies.

One is their compatibility with legacy systems. New technologies can be deployed stepwise: advanced robotic and/or 3D printing solutions, sensors and various devices can be added to existing production systems without jeopardising their functionality (Colombo *et al.* 2014). Since scalability, modularity and interoperability are important attributes of cyber-physical systems, this allows for a progressive reconfiguration of existing production facilities, successively transforming them into 'factories of the future'. Compatibility with legacy production systems is expected to prompt parent companies to upgrade their existing manufacturing assets in factory economies, instead of establishing brand new 'Industry 4.0' facilities in their home countries.

14. According to press releases of the Hungarian Outsourcing Association (www.hoa.hu), both the number of and employment in shared services centres have sharply increased in Hungary. In 2016 their number reached 90, with total employment above 35,000.

A further opportunity is that deployment, operation and maintenance of advanced manufacturing solutions require the development of substantial engineering capabilities at hosting units (at subsidiary level). Local capability accumulation may, in turn, have non-negligible multiplier effects, prompting parent companies to delegate further knowledge-intensive assignments, such as the programming of industrial robots or process development through the experimental analysis, measurement and testing, modelling and simulation of manufacturing processes.

4. Experience with Industry 4.0 at MNC manufacturing subsidiaries in Hungary – Sample and interview results

Applying a purposeful sampling method (Patton 1990) with the aim of selecting information-rich cases, i.e. companies whose cases promise insights into issues related to our research, we selected eight companies for in-depth interviews. Furthermore, two interviews were carried out with representatives of a Hungarian research institution specialised in software solutions related to Industry 4.0.

The eight large[15] foreign-owned companies operate in the automotive and electronics industries, and two of them can also be classified as technology producers, as they are specialised in the manufacture of intelligent sensors, data acquisition hardware and software, programmable automation controllers and automated test systems.

We selected MNC subsidiaries as they are spearheading the introduction of new technologies. According to the European Commission's Digital Economy and Society Index (European Commission 2016), Hungary ranks 20th of the 28 EU Member States, and is lagging behind, in particular in terms of businesses integrating digital technology.

An interview guide containing predominantly open-ended questions allowed interviewees to provide a detailed description of their experiences with the new technologies. We started by surveying management awareness of Industry 4.0 trends and technologies, wanting to find out whether a systematic digital strategy was behind the implementation of new technologies in the Hungarian plants, and whether further investments – aligned with a more or less predetermined roadmap – were expected. Next, we asked about the purpose of these investments (cost-cutting versus improving quality and efficiency).

The interviews, 45 to 60 minutes in length, were conducted between April and July 2016. Interviewed managers were the chief executive officers, division leaders or chief technology officers of the Hungarian subsidiaries. To preserve anonymity, neither company names nor main products will be specified.

15. Average turnover of the sampled companies (n = 8) amounted to €335 million in 2015, while their average headcount was 1,281.

4.1 Awareness and implementation of Industry 4.0 technologies

The first finding that crystallised during the interviews was the relatively high degree of preparedness of the surveyed organisations to adopt Industry 4.0 technologies. The managers interviewed were not only aware of the new technological trends represented by Industry 4.0, but had already invested heavily in the new technologies.

Over and above the two specialised technology producers, many of the surveyed companies also turned out to be technology producers, developing in-house measurement and testing equipment for their production processes. As cyber-physical production systems are not off-the-shelf solutions, they cannot be fully specified in the planning stage and usually need to be extended and adapted over the course of their deployment, and almost continuously modified during operation. Consequently, the IT staff of manufacturing companies are involved in the customisation, operational integration and subsequent adaptation of the purchased solutions (reprogramming).

The interviews indicated that the adoption of Industry 4.0 solutions is not a 'yes or no' issue, but rather an evolutionary journey encompassing a multitude of advanced techniques. Indeed, in several companies the implementation of production automation solutions, the use of sensors and the incorporation of traceability solutions in the manufacturing processes started more than a decade ago. Networked equipment controlled by computing algorithms has similarly featured in the production systems of the selected firms for at least a decade. The main innovations mentioned by the interviewed executives cover three aspects. First, the acquisition of a wide variety of production parameters for analysis by advanced data mining techniques. The second, related innovation is the unprecedented transparency of the whole production process, while the third involves man–machine collaboration (robots are no longer behind fences). Nevertheless, the current hype about Industry 4.0, as one of the managers interviewed explained, is not due to the alleged *revolutionary* character of the technologies, but to their better visibility. The costs of advanced solutions have declined below a threshold level, triggering a virtuous circle in terms of the diffusion, cost and improved quality of the individual solutions.

Nevertheless, there is a long way to go between adopting basic Industry 4.0 applications and becoming a fully integrated business unit, where communicating and collaborating devices are networked and integrated in MNC-wide systems, and where computational algorithms autonomously monitor, control and manage (intervene in) the manufacturing system – including the related support processes.

The production systems of several of the surveyed technology users[16] can be labelled as 'factory of the future' showcases (though a strong selection bias applies). They are

16. Note that there are some intra-sample disparities in this respect. The surveyed companies have all implemented industrial automation solutions, though there are differences in the degree thereof. While some have invested solely in standard robotic solutions, others are already experimenting with human–robot collaboration systems. The surveyed companies gather data generated during the production process, but in most cases business analytics are implemented by parent companies – though some subsidiaries recently invested in business analytics solutions.

not only characterised by a high level of automation – especially with respect to high-precision, physically difficult, high-volume, repetitive tasks, but also equipped with cyber-physical systems with embedded sensing, measurement and data extraction solutions. Some companies apply advanced decision-support systems, and rely on the 3D visualisation of manufacturing, assembly and related shop-floor logistics processes (virtual factory).

One explanation of the relatively high level of Industry 4.0 technology adoption – at least among the flagship companies surveyed[17] – is Hungary's status as an FDI-driven 'factory economy'. On the one hand, flagship MNCs obviously apply global corporate standards, including standardised systems architecture, standardised technology modules and standardised work practices, also at their manufacturing subsidiaries.[18] Moreover, industry standards prescribing increased product traceability also account for the rapid diffusion of the new manufacturing and testing technologies.

On the other hand, digitalising the shop-floor and making factories smart is easier and quicker by orders of magnitude than implementing 'headquarter economy'-type tasks related to digital transformation (DT). In factory economies, DT involves the application of digital tools and methods to automate, enhance and optimise the existing way of working. Conversely, in headquarter economies, DT refers to new ways of working, to a fundamental transformation of the rules of the game, e.g. a transition to platform competition[19]; entry into new sectors; business model innovation; innovative digital services provision and product differentiation based on a big-data/business analytics-based thorough knowledge of customers (cf. Porter and Heppelmann 2014). The main purpose of digitalisation in headquarter economies is to enhance flexibility and responsiveness through creating, managing and implementing *new processes*. Conversely, in factory economies, the main purpose of technology adoption is to achieve operational excellence in *existing processes* (see below). Consequently, DT in factory economies – at least in their FDI-driven segments – is much more rapid than in headquarter economies.

17. As emphasised by the technology producers interviewed, there are large size- and ownership-specific differences in the adoption of Industry 4.0 technologies.
18. Obviously, there are intra-MNC differences with respect to the deployment of specific solutions. For example, the pilot introduction of some new technological solutions usually takes place in manufacturing facilities at the HQ's location.
19. Industry platforms connect various actors belonging to an innovation ecosystem. Platform participants co-create new products and services around a core technology infrastructure (e.g. Apple's app developer eco-system), share information and/or implement a variety of transactions. Platform technologies are licensed to ecosystem partners (e.g. hardware or software vendors or service providers) that compete and collaborate to grow within the platform ecosystem. Network externalities are a key factor of success: the more users and ecosystem partners enter the platform, the higher the benefits. Examples of platforms include Amazon, Uber, Airbnb, Facebook (for more on different forms of platforms and platform competition, see Gawer and Cusumano 2014; Salazar 2015; and on a large industrial company shifting to platform competition, see Agarwal and Brem 2015).

4.2 Purpose of technology adoption

Another finding of the interviews was that (except for a few cases) even the advanced local users of Industry 4.0 applications lacked a systematic digital strategy. Primarily targeting specific outcomes/challenges, they have invested in selected advanced solutions, without aligning their investment decisions with a defined digital transformation roadmap. The challenges mentioned during the interviews fall into four categories:

1. Shop-floor technological problems. Examples of shop-floor technological problems included inefficient process scheduling, excessive downtime, long changeover times, quicker-than-expected tool wear, product defects, low overall equipment effectiveness, variations in cycle times due to low process stability, etc.

2. Shortages of skilled labour. Labour shortages (with respect to both operators and engineers) constituted one of the most commonly mentioned challenges. Together with the decreasing cost of industrial robots, this was an important driver for some of the surveyed companies to adopt industrial automation solutions.[20]

3. Increased production complexity. The solution to this problem was the implementation of advanced production planning and scheduling systems, integrated within the core enterprise resource planning (ERP) system.

4. Increased customer requirements in terms of time, variety, costs and flexibility.

Over and above addressing operational challenges, the surveyed companies' quest for a general improvement in both productivity and operational excellence was also uniformly stressed as a key motivation for investing in Industry 4.0 technologies.[21] Examples include the deployment of a visual recognition system combined with machine learning for quality inspection (to identify anomalies). Furthermore, seeking to prevent problems emerging during production and to minimise maintenance costs, Industry 4.0 solutions (e.g. computerised maintenance management systems relying on big data analytics or simulation-based smart algorithms) have been applied to predict and control any problems.

Although cost reduction was not among the explicitly stated purposes, this factor also figured among the expected benefits. It was expressed indirectly, in the form of the expected rapid return on investments in industrial robots, triggering a reduction in the number of operators needed.

20. This increasingly pressing problem is not limited to Hungary. According to Sondergaard *et al.*'s (2012) investigations, the shortage of skilled manual workers emerged as one of the most important constraints to company expansion throughout Central Europe.

21. One of the managers interviewed remarked: 'One of our objectives in deploying the automated optical inspection system and the production planning and scheduling software was to achieve a productivity level corresponding to 95% of the level of our parent company's production facility in Germany.'

Nevertheless, efficiency gains (reductions of machine downtime and interim storage; close-to-optimal assignment of work and the efficient use of resources such as material and energy) were apparently a more important objective of investing in smart systems than mere cost reduction.

4.3 Impact on jobs

The interviews made it clear that new relatively low-cost robots have indeed reduced demand for operators in the surveyed companies. Nevertheless, as emphasised by the executives interviewed, the impact of the new technological solutions on jobs is not straightforward, needing a nuanced assessment. On the one hand, these robots help overcome labour shortages. On the other hand, the reduction of demand for operators related to specific activities has not resulted in overall job losses. It was rather manifested in relative terms, in terms of the labour content per unit of output. Over the surveyed period, between 2012 and 2015, sample companies have considerably expanded their production, necessitating the expansion of their workforces.[22] Hence, the operators whose tasks had been automated have been reassigned to other production activities.

At the same time, some smart solutions are taking over white-collar tasks. For example, automated data extraction solutions have freed up engineers from preparing daily reports on selected production parameters. The introduction of big data analytics solutions has relieved engineers who used to spend a couple of hours each week studying production data and trying to discover patterns revealing the root causes of disruptions and other anomalies. Production planning and scheduling software has similarly redefined the jobs of engineers who used to be responsible for these tasks. Quality control has become increasingly automated.

Some interviewees mentioned that this redefinition of engineers' tasks and the expectation of them being able to work supported by smart systems have sometimes necessitated 'qualitative changes' in the white-collar workforce. On the other hand, engineers with adequate technical and non-technical skills are experiencing increasingly intensive *intra-firm competition* for their talents: they keep being tempted to move to (regional or central) HQ premises to take up more challenging, more knowledge-intensive (and obviously better-paid) activities there. Assessing this phenomenon from a 'factory economy' perspective, as some of the executives interviewed did, this may jeopardise the perspectives of a subsidiary upgrading its operations.

A common observation of the managers interviewed was that focusing on technology-driven relocation of tasks and job losses was not the right approach to our investigation. In an MNC's production system, characterised by end-to-end digital integration (along the entire value chain), the question where a specific processing task is performed is losing relevance, at least from an HQ perspective. Even internalisation (ownership-based control) has become less relevant than before, due to advanced communication and virtualisation technologies. From an HQ perspective, the sole factors of importance

22. Over this period, headcounts in the sample companies increased on average by 22.6%.

are *access* to capacities and competences and end-to-end *control* of the processes. Of course, from the perspective of local subsidiaries the pursuit of an ‘entrepreneurial’ subsidiary strategy (Birkinshaw and Hood 1998) is of crucial importance in order to withstand the intensified selection mechanisms triggered by technological change. Aiming to maintain or improve their position, Hungarian subsidiaries strive to spearhead the implementation of new technologies. Several interviewed executives remarked that pioneer adopters within the MNC organisation have the chance of becoming ‘Industry 4.0 competence centres’, with local experts responsible for transferring best practices to partner subsidiaries.

As for the impact of new technologies on jobs, the executives interviewed maintained that this research focus is irrelevant for companies faced with global competition. Implementing new technologies is simply a must, as otherwise competitiveness will soon be eroded and markets lost. The imperative of operational excellence requires the deployment of robotic solutions, for example to achieve high-precision machining and welding. As big data and simulation-based computing applications addressing multiple aspects of operational excellence are proliferating, technology-push factors are just as important determinants of the adoption of new solutions as demand-pull ones.

5. Conclusion and policy implications

Based on an overview of the literature on the features and expected impacts of Industry 4.0 technologies, this paper developed a rather pessimistic scenario, from the perspective of ‘factory economies’ in general and CEE countries in particular. In this scenario, economies at an intermediate development level were set to be hit hard by the new manufacturing technologies. These technologies would lead to massive job losses which may not be compensated by the creation of new skill-intensive jobs.

It was also predicted that some of the relatively advanced assignments gained by upgraded local manufacturing subsidiaries might be lost through reshoring, relocation or automation. Consequently, selected past upgrading achievements might be repealed.

Empirical evidence has however only partly supported these pessimistic predictions. Interview findings suggest that instead of relocating / reshoring production, MNC owners have (*so far*) tended to upgrade their existing production facilities by implementing Industry 4.0 solutions. This is made possible by the fact that these technologies are (or can be made) compatible with legacy production systems and legacy technologies. Moreover, when production was expanded through establishing greenfield facilities, these were characterised by advanced cyber-physical production systems.

Note that the implementation of advanced manufacturing technologies (upgrading technology in local subsidiaries) is only seemingly confined to improving the given subsidiaries’ *production capability*. With the advent of Industry 4.0, technological capability and production capability have become more strongly interwoven than ever before (Tassey 2014), with the deployment of new technological solutions requiring subsidiaries to invest considerable effort in implementing them. As the experience of some of the surveyed companies illustrates, demonstrated capabilities during the deployment of Industry 4.0 technologies have opened up additional opportunities for local engineers to participate in MNC-wide technology development activities. Instead of reshoring or centralising knowledge-intensive activities, MNC owners have delegated additional sophisticated engineering tasks to their local subsidiaries – *provided they have the required competences*.

Consequently, it is fair to claim that, *with the advent of Industry 4.0, the disjunction between technology use and technology generation that used to characterise the transformation and integration decades of the CEE region,*[23] *has been alleviated*.

Interviews indicated that the newly implemented solutions have indeed led to reduced demand for operators in the given activities, and it is anticipated that this trend will continue. At the same time, production expansion in the surveyed companies has increased overall demand both for skilled operators and for highly skilled engineers with a deep understanding of the production system (how its individual parts are related to each other and to the system as a whole) and of the tools and techniques needed to test and maintain the production system. This has made the labour shortages faced by local subsidiaries for some time even more pressing than before. Aggravating problems through labour shortages suggests that in the 'second machine age' (Brynjolfsson and McAfee 2014), the education system of Hungary has fallen behind in 'the race between education and technology' (Goldin and Katz 2008).

Overall, it can be concluded that in the short term, in our small sample of high-flying subsidiaries, (beneficial) *retention mechanisms* have prevailed over harmful-for-the-given-subsidiaries *selection* and *reconfiguration mechanisms*. It remains to be seen, however, whether medium- and longer-term reconfigurations of GVC architectures triggered by technological change will reinforce or rather mark down these initial developments.

The main policy implication of the results is that immediate action is needed to reform education systems in factory economies. Delays in boosting the supply of adequately skilled workers and aligning training with skill demands may eventually hinder the adoption of advanced manufacturing technologies, leading to activities being relocated. As one of the interviewees remarked, 'We badly need "vocational schools 4.0", where future workers are educated to use modern technologies, and will possess, at least, some basic programming skills.'

It can be concluded that it is not technological progress in the field of Industry 4.0 per se that could hit factory economies hard: they might lose out in the digital transformation of manufacturing if their labour markets remain too rigid and their education systems fail to adapt to the evolving demand for knowledge.

23. See Kravtsova and Radosevic (2012) who argued that productivity growth in the CEE region was based predominantly on improvements to economic actors' production capabilities and not on their enhanced technological or innovation capabilities.

In addition to education (e.g. improving IT literacy and promoting lifelong learning) and public awareness-raising programmes, government policy should promote overall Industry 4.0 readiness by several means. The first is strategic planning: the elaboration of country-specific, and also industry-specific Industry 4.0 development plans. Although direct emulation of best practices in other countries (e.g. Germany) is prone to failure (an emphasis should instead be put on context-based policy learning), there are some general 'recipes' that may prove to be useful constituents of Industry 4.0 strategies in all CEE economies.

Another general policy recommendation is to encourage companies to *use* the data generated by their state-of-the-art production systems, i.e. developing capabilities in data analytics. This would ensure that investment in Industry 4.0 technologies indeed results in improved productivity and resource efficiency.

Finally, policy should promote participation in European Industry 4.0 initiatives related to research, pilot programmes and demonstration projects.

References

Acemoglu D. and Restrepo P. (2016) The race between machine and man: implications of technology for growth, factor shares and employment. http://pascual.scripts.mit.edu/research/02/ManVsMachine.pdf

Agarwal N. and Brem A. (2015) Strategic business transformation through technology convergence: implications from General Electric's industrial internet initiative, International Journal of Technology Management, 67 (2–4), 196–214.

Arntz M., Gregory T. and Zierahn U. (2016) The risk of automation for jobs in OECD countries: a comparative analysis, OECD Social, Employment and Migration Working Papers No. 189, Paris, OECD Publishing. http://dx.doi.org/10.1787/5jlz9h56dvq7-en

Artner A. (2005) Production technology and competitiveness in the Hungarian manufacturing industry, Acta Oeconomica, 55 (3), 317–340.

Autor, D.H. (2015) Why are there still so many jobs? The history and future of workplace automation. The Journal of Economic Perspectives, 29 (3), 3–30.

Baldwin R. and Lopez-Gonzalez J. (2015) Supply-chain trade: a portrait of global patterns and several testable hypotheses, The World Economy, 38 (11), 1682–1721.

Bard J. F., Jia, S., Chacon R. and Stuber J. (2015) Integrating optimisation and simulation approaches for daily scheduling of assembly and test operations, International Journal of Production Research, 53 (9), 2617-2632.

Bartlett C. A. and Ghoshal S. (1986) Tap your subsidiaries for global reach, Harvard Business Review, 64 (6), June, 87–94.

Benzell S. G., Kotlikoff L. J., LaGarda G. and Sachs J. D. (2015) Robots are us: some economics of human replacement, NBER Working Paper No. 20941, Cambridge, MA, National Bureau of Economic Research.

Berman B. (2012) 3-D printing: the new industrial revolution, Business Horizons, 55 (2), 155–162.

Bernard A. B., Smeets V. and Warzynski F. (2016) Rethinking deindustrialization, NBER Working Paper No. 22114, Cambridge, MA, National Bureau of Economic Research.

Birkinshaw J. (1996) How multinational subsidiary mandates are gained and lost, Journal of International Business Studies, 27 (3), 467–495.
Birkinshaw J. and Hood N. (1998) Multinational subsidiary evolution: capability and charter change in foreign-owned subsidiary companies, Academy of Management Review, 23 (4), 773–795.
Bonin H., Gregory T. and Zierahn U. (2015) Übertragung der Studie von Frey/Osborne (2013) auf Deutschland, ZEW Kurzexpertise No. 57, Mannheim, Zentrum für Europäische Wirtschaftsforschung.
Brettel M., Friederichsen N., Keller M. and Rosenberg M. (2014) How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 8 (1), 37-44.
Brynjolfsson E. and McAfee A. (2014) The second machine age: work, progress, and prosperity in a time of brilliant technologies, New York, WW Norton & Company.
Cano-Kollmann M., Cantwell J., Hannigan T.J., Mudambi R. and Song J. (2016) Knowledge connectivity: an agenda for innovation research in international business, Journal of International Business Studies, 47 (3), 255–262.
Chandler A.D. (1962) Strategy and Structure, Cambridge, MA, MIT Press.
Chui M., Manyika J. and Miremadi M. (2015) Four fundamentals of workplace automation, McKinsey Quaterly, November 2015. http://www.mckinsey.com/business-functions/business-technology/our-insights/four-fundamentals-of-workplace-automation
Colombo A. W., Karnouskos S. and Bangemann T. (2014) Towards the next generation of industrial cyber-physical systems, in Colombo A., Bangemann T., Karnouskos S., Delsing J., Stluka P., Harrison R., Jammes F. and Lastra J. L. (eds.) Industrial cloud-based cyber-physical systems, Springer International Publishing, 1–22.
Contractor F. J., Kumar V., Kundu S. K. and Pedersen T. (2010) Reconceptualizing the firm in a world of outsourcing and offshoring: The organizational and geographical relocation of high-value company functions, Journal of Management Studies, 47 (8), 1417–1433.
Damijan J., Kostevc Č. and Rojec M. (2015) Bright past, shady future? Past and potential future export performance of CEE countries in a comparative perspective, Post-Communist Economies, 27 (3), 306–335.
Dörrenbächer C. and Gammelgaard J. (2010) Multinational corporations, inter-organizational networks and subsidiary charter removals, Journal of World Business, 45 (3), 206–216.
Dulleck U., Foster N., Stehrer R. and Woerz J. (2005) Dimensions of quality upgrading, Economics of Transition, 13 (1), 51-76.
Economist (The) (2016) Call centres: the end of the line, 6 February 2016. https://www.economist.com/news/international/21690041-call-centres-have-created-millions-good-jobs-emerging-world-technology-threatens
European Commission (2016) Digital scoreboard. https://ec.europa.eu/digital-single-market/en/digital-scoreboard
Farkas, B. (2011) The Central and Eastern European model of capitalism. Post-Communist Economies, 23 (1), 15–34.
Ford S. L. (2014) Additive manufacturing technology: potential implications for U.S. manufacturing competitiveness, Journal of International Commerce and Economics, September 2014. https://www.usitc.gov/journals/Vol_VI_Article4_Additive_Manufacturing_Technology.pdf
Frey C. B. and Osborne M. A. (2013) The future of employment: how susceptible are jobs to computerisation? http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf

Frost T. S., Birkinshaw J. M. and Ensign P. C. (2002) Centers of excellence in multinational corporations, Strategic Management Journal, 23 (11), 997–1018.
Galambos P., Csapó Á., Zentay P., Fülöp I. M., Haidegger T., Baranyi P. and Rudas I. J. (2015) Design, programming and orchestration of heterogeneous manufacturing systems through VR-powered remote collaboration, Robotics and Computer-Integrated Manufacturing, 33, June, 68–77.
Garrett B. (2014) 3D printing: new economic paradigms and strategic shifts, Global Policy, 5 (1), 70–75.
Gawer, A. and Cusumano M. A. (2014) Industry platforms and ecosystem innovation, Journal of Product Innovation Management, 31 (3), 417–433.
Goldin C. and Katz L. F. (2008) The race between education and technology, Boston, Harvard University Press.
Gress D. R. and Kalafsky R. V. (2015) Geographies of production in 3D: theoretical and research implications stemming from additive manufacturing, Geoforum, 60, 43-52.
Gyulai D., Kádár B. and Monosotori L. (2015) Robust production planning and capacity control for flexible assembly lines, IFAC-PapersOnLine, 48 (3), 2312–2317.
Hermann M., Pentek T. and Otto B. (2015) Design principles for Industrie 4.0 scenarios: a literature review, Working Paper No. 1, Dortmund, Technische Universität Dortmund. http://www.snom.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design-Principles-for-Industrie-4_0-Scenarios.pdf
Holmström J., Holweg M., Khajavi S. H. and Partanen J. (2016) The direct digital manufacturing (r) evolution: definition of a research agenda, Operations Management Research, 9 (1-2), 1–10.
Jensen P. D. Ø. and Pedersen T. (2011) The economic geography of offshoring: the fit between activities and local context, Journal of Management Studies, 48 (2), 352-372.
Kagermann H., Helbig J., Hellinger A. and Wahlster W. (2013) Recommendations for implementing the strategic initiative INDUSTRIE 4.0: securing the Future of German Manufacturing Industry Forschungsunion. http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf
Ketokivi, M. and Ali-Yrkkö J. (2009) Unbundling R&D and manufacturing: postindustrial myth or economic reality?, Review of Policy Research, 26 (1-2), 35–54.
Koza M. P., Tallman S. and Ataay A. (2011) The strategic assembly of global firms: a microstructural analysis of local learning and global adaptation, Global Strategy Journal, 1 (1-2), 27–46.
Kravtsova V. and Radosevic S. (2012) Are systems of innovation in Eastern Europe efficient?, Economic Systems, 36 (1), 109–126.
Lacity M. and Willcocks L. (2015) Robotic process automation: the next transformation lever for shared services, The Outsourcing Unit Working Paper Series No. 7, London, London School of Economics and Political Science.
Lanz R., Miroudot S. and Nordås H. (2011) Trade in tasks, OECD Trade Policy Working Papers No. 117, Paris, OECD Publishing.
Larsen M. M., Manning S. and Pedersen T. (2011) The hidden costs of offshoring: the impact of complexity, design orientation and experience, Academy of Management Proceedings, http://ssrn.com/abstract=1823705
Lee J., Lapira E., Bagheri B. and Kao H. A. (2013) Recent advances and trends in predictive manufacturing systems in big data environment, Manufacturing Letters, 1 (1), 38–41.

Linares-Navarro E., Pedersen T. and Pla-Barber J. (2014) Fine slicing of the value chain and offshoring of essential activities: empirical evidence from European multinationals, Journal of Business Economics and Management, 15 (1), 111–134.
Manyika J., Chui M., Bughin J., Dobbs R., Bisson P. and Marrs A. (2013) Disruptive technologies: advances that will transform life, business and the global economy, New York, McKinsey Global Institute.
Millward S. (2016) Foxconn axes 60,000 jobs in one Chinese factory as robots take over, TeChinAsia, 26 May 2016. https://www.techinasia.com/foxconn-robots-china-job-losses
Monostori L. (2015) Cyber-physical production systems: roots from manufacturing science and technology, at Automatisierungstechnik, 63 (10), 766 776.
Nelson R.R. and Winter S.G. (1982) An evolutionary theory of economic change, Cambridge, Harvard University Press.
Nölke A. and Vliegenthart A. (2009) Enlarging the varieties of capitalism: the emergence of dependent market economies in East Central Europe, World Politics, 61 (4), 670-702.
Oettmeier K. and Hofmann E. (2016) Additive manufacturing technology adoption: an empirical analysis of general and supply chain-related determinants, Journal of Business Economics, 87 (1), 97-124.
Oldenski L. (2015) Reshoring by US firms: what do the data say?, Peterson Institute for International Economics Policy Brief No. 15-14, Washington, DC. https://piie.com/publications/pb/pb15-14.pdf
Ong S. K. and Nee A. Y. C. (eds.) (2013) Virtual and augmented reality applications in manufacturing, London, Springer.
Patton M. Q. (1990) Qualitative evaluation and research methods, Newbury Park, CA, Sage Publications.
Pavlínek P., Domański B. and Guzik R. (2009) Industrial upgrading through Foreign Direct Investment in Central European automotive manufacturing, European Urban and Regional Studies, 16 (1), 43–63.
Pentenrieder K., Bade C., Doil F. and Meier P. (2007) Augmented reality-based factory planning – an application tailored to industrial needs, paper presented at the 6th IEEE and ACM International Symposium on Mixed and Augmented Reality, Nara, 13-16 November 2007, 31-42.
Petrick, I. J. and Simpson T. W. (2013) 3D printing disrupts manufacturing: how economies of one create new rules of competition, Research-Technology Management, 56 (6), 12-16.
Porter M. E. and Heppelmann J. E. (2014) How smart, connected products are transforming competition, Harvard Business Review, 92, November, 64 88.
Porter M. E. and Heppelmann J. E. (2015) How smart, connected products are transforming companies, Harvard Business Review, 93, October, 96–114
Roland Berger Strategy Consultants (2014) Industry 4.0 – The new industrial revolution - how Europe will succeed. https://www.rolandberger.com/en/Publications/pub_industry_4_0_the_new_industrial_revolution.html
Rosochowski A. and Matuszak A. (2000) Rapid tooling: the state of the art, Journal of Materials Processing Technology, 106 (1-3), 191–198.
Rugman A. M. and Verbeke A. (2001) Subsidiary-specific advantages in multinational enterprises, Strategic Management Journal, 22 (3), 237–250.
Sachs J. D., Benzell S. G. and LaGarda G. (2015) Robots: curse or blessing? A basic framework, NBER Working Papers No. 21091, Cambridge, MA, National Bureau of Economic Research.

Salazar A. J. (2015) Platform competition: a research framework and synthesis of game-Theoretic Studies. https://ssrn.com/abstract=2565337
Sass M. and Fifekova M. (2011) Offshoring and outsourcing business services to Central and Eastern Europe: some empirical and conceptual considerations, European Planning Studies, 19 (9), 1593–1609.
Sass M. and Szalavetz A. (2013) Crisis and upgrading: the case of the Hungarian automotive and electronics sectors, Europe-Asia Studies, 65 (3), 489–507.
Sass M. and Szalavetz A. (2014) R&D-based integration and upgrading in Hungary, Acta Oeconomica, 64 (Supplement 1), 153–180.
Schuh G., Reuter C., Hauptvogel A. and Dölle C. (2015) Hypotheses for a theory of production in the context of Industrie 4.0, in Brecher C. (ed.) Advances in production technology, Dordrecht, Springer International Publishing, 11–23.
Sondergaard L., Murthi M., Abu-Ghaida D., Bodewig C. and Rutkowski J. (2012) Skills, not just diplomas: managing education for results in Eastern Europe and Central Asia, Washington, DC, The World Bank.
Szalavetz A. (2016a) Post-crisis developments in multinational corporations' global organisations, Competition and Change, 20 (4) 221–236.
Szalavetz A. (2016b) Chronicle of a revolution foretold, Studies in International Economics (Special issue of Külgazdaság), 2 (2), 63–81.
Szalavetz A. (2015) Upgrading and subsidiary autonomy: experience of Hungarian manufacturing companies, Japanese Journal of Comparative Economics, 52 (2), 1–19.
Tassey G. (2014) Competing in advanced manufacturing: the need for improved growth models and policies, Journal of Economic Perspectives, 28 (1), 27–48.
Valenduc G. and Vendramin P. (2016) Work in the digital economy: sorting the old from the new, Working Paper No. 3, Brussels, ETUI.
Váncza J., Monostori L., Lutters D., Kumara S. R., Tseng, M., Valckenaers P. and Van Brussel H. (2011) Cooperative and responsive manufacturing enterprises, CIRP Annals-Manufacturing Technology, 60 (2), 797–820.
WEF (2016) The future of jobs. Employment, skills and workforce strategy for the fourth industrial revolution, Geneva, World Economic Forum.

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