ARTICLE IN PRESS

Technological Forecasting & Social Change xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Industry 4.0 and capability development in manufacturing subsidiaries

Andrea Szalavetz

Institute of World Economics, Hungarian Academy of Sciences, 4, Tóth Kálmán utca, Budapest, Hungary

ARTICLE INFO

Keywords:
Industry 4.0
Upgrading
Manufacturing subsidiary
Capability development
Hungary

ABSTRACT

This paper investigates whether advanced manufacturing technologies (AMT) can modify the patterns of upgrading in manufacturing subsidiaries operating in FDI hosting factory economies. Does the digital transformation of local manufacturing engender the accumulation of local technological and R&D capabilities, or the beneficial impact of AMT remains confined to production capability?

Analysis is based on primary data collected through in-depth interviews with a sample of high-flying manufacturing subsidiaries in Hungary, complemented with interviews with AMT providers.

We find that AMT have spectacularly improved all components of production capability. AMT redefined the boundaries of production activities and incited a fusion of selected technological activities in production activities. AMT deployment has automated selected tacit knowledge-intensive technological activities, making the related subsidiary-level capabilities obsolete. Conversely, other local technological activities have become more knowledge-intensive than before.

AMT propelled the upgrading of subsidiary-level R&D capabilities by supporting specific R&D activities and by acting as enabler of innovation collaboration. AMT created an integrated development environment and thus reduced the risks related to the decentralisation of R&D. Altogether, AMT adoption contributed to subsidiary R&D capability becoming 'revealed' and further upgraded through learning by doing.

1. Introduction

Contrary to intuitive expectations, preliminary evidence suggests that, apart from a couple of high-publicised cases (e.g. Cruickshank, 2016), advanced manufacturing technologies (AMT) have so far failed to trigger a massive backshoring of production activities from foreign direct investment hosting 'factory economies' (Baldwin, 2013) to investors' home countries (European Reshoring Monitor, 2017; Kinkel, 2014).

Instead of backshoring, the previously offshored production capacities are being upgraded in host locations (Tables 1 and 2). In Central and Eastern Europe (CEE) for example, in selected segments of the economy characterised by a high share of foreign equity (such as the automotive and electronics industries), the local manufacturing subsidiaries of global companies have rapidly implemented AMT and digitised their existing production systems.

Discussing the implications of these location decisions seems both timely and necessary, especially in the light of evolving functional interdependencies within global value chains. Consider, for example, that advanced manufacturing displays important colocation synergies with R&D: production necessitates close interactions with product and process-related research and development (Ivarsson et al., 2017; Pisano and Shih, 2012; Tassey, 2014). These scholars argue that the erosion of production capabilities in advanced economies that was brought about by their prior offshoring/outsourcing of routine and labour-intensive activities, will beget the loss of advanced activities as well, together with valuable complementary capabilities.

> "*The US printed circuit board industry was once relatively labor-intensive, which led to its off-shoring. Today, its production process is highly automated, with low unit labor content, but the transition to automated production happened in other countries where downstream industries are located. Thus, the majority of the global industry remains in those locations (Asia) near the subsequent tiers in the electronics supply chain—component and final product.*"
>
> (Tassey, 2014, p. 34)

From the perspective of host economies, the flipside of the same coin suggests that the digital transformation of manufacturing activities will open up unprecedented upgrading opportunities for local manufacturing subsidiaries. The attraction of advanced production activities will prompt not only new waves of technology inflow through foreign investors' AMT transfers, but will also intensify the local accumulation of technological capabilities.

This paper sets out to investigate this latter argument, i.e. whether new manufacturing technologies will indeed modify the patterns of upgrading in FDI hosting factory economies in general, and in Central

---

E-mail address: szalavetz.andrea@krtk.mta.hu.

https://doi.org/10.1016/j.techfore.2018.06.027
Received 31 July 2017; Received in revised form 22 May 2018; Accepted 13 June 2018

Please cite this article as: Szalavetz, A., Technological Forecasting & Social Change (2018), https://doi.org/10.1016/j.techfore.2018.06.027

Table 1
Estimated yearly shipments of multipurpose industrial robots (number of units).
Source: IFR

	2014	2015	2016[a]	2019[a]
CEE	4643	5976	7550	11,300
China	57,096	68,556	90,000	160,000
Germany	20,051	20,105	21,000	25,000
Spain	2312	3766	4100	5100

[a] Forecast.

Table 2
Robot density in manufacturing (number of multipurpose industrial robots per 10,000 employees in manufacturing), 2015.
Source: IFR

Czech Republic	93	Germany	301
Slovakia	79	Austria	128
Hungary	n.a.[a]	USA	176
Spain	150	Japan	305

[a] In IFR's yearbooks on industrial robots no data are available about Hungary. According to the interviews made in the framework of this research project, the estimated number of multipurpose industrial robots deployed in Hungary is ~5000. Calculating robot density (number of multipurpose industrial robots per 10,000 employees) and using 2015 data on total manufacturing employment, this would result in a robot density of 55.5. If data on 'total employment in manufacturing companies with more than five employees' are taken into account, robot density in Hungary would be 75.8. If we calculate with data on 'blue collar employees in manufacturing companies with more than five employees', the resulting robot density is 103.8. Finally if we use the 'number of operators, assembly workers and vehicle drivers employed in total manufacturing' (all companies), robot density would be 90.4. (Source: author's calculation from Central Statistical Office data).

and Eastern Europe, in particular. Our point of departure is Kravtsova and Radosevic's (2012) argument, substantiated also by several other scholars (e.g. Inzelt, 2000; Narula and Guimón, 2010) that foreign investors' massive technology transfers and the accompanying knowledge inflows have mainly enhanced production (technology using) capability in CEE. Conversely, local technological (technology development) capability has not improved much. The purpose of this paper is therefore to examine whether in contrast to prior experience, AMT transfer and the digital transformation of manufacturing could also enhance technological capability building in manufacturing subsidiaries.

More specifically, we explore AMT-triggered changes in the nature of work and in the skill-intensity of activities at a sample of Hungarian manufacturing subsidiaries. We categorise these changes in a pertinent capability development framework (Bell and Pavitt, 1993; Kim, 1997; Radosevic and Yoruk, 2018).

To anticipate the findings of our research, we argue that the digital transformation of manufacturing results in substantially improved local production capability. At the same time, the content of 'production capability' undergoes non-negligible transformation. This calls for an evolutionary approach for the analysis of the actual concept of *production capability*.

AMT deployment has a Janus face-like effect on subsidiary technological capabilities. On one hand AMT support or even automate selected tacit knowledge-intensive technological activities. Part of the related capabilities will thus become obsolete. On the other hand, the nature and the composition of post-AMT-adoption technological capabilities will change: they become more knowledge-intensive than before.

As for the upgrading of subsidiary-level R&D capabilities, AMT adoption fosters these processes both directly and indirectly. The increased data-intensity of processing activities, and a more-intensive-than-before application of computer science (e.g. modelling, advanced simulation, big data extraction and –analysis) in operations requires the accumulation of the related technological and R&D capabilities also by actors with a dominantly production mandate. The complexity-driven multiplication of absorption-related technological tasks also augments the technological and scientific sophistication of subsidiary engineers' and researchers' work. Technology absorption, i.e. the deployment and the integration of new solutions/equipment in the existing production system creates additional technological problems – to be addressed by indigenous R&D. The more complex the production system, the more absorption-related technological problems will emerge. In an AMT context, the knowledge-intensive assignments of local engineers will multiply.

Additionally, AMT solutions enable the decentralisation of corporate technological and R&D activities by supporting global R&D collaboration (through 3D visualisation, cloud-based solution provision, data sharing and other virtual collaboration tools). Innovation collaboration among networked partners will thus take place in an *integrated development environment*. This reduces the risks related to the decentralisation of R&D activities. Consequently, AMT adoption represents an opportunity for subsidiaries to demonstrate their technological and R&D competences.

In order to develop these arguments, we proceed as follows. First, the related theoretical background is briefly summarised and our conceptual framework for the relation between AMT and manufacturing subsidiary-level capability development presented (Section 2). In Section 3, the method of empirical data collection is outlined and the sample of interviewees introduced. This is followed by the presentation and discussion of the empirical findings (Section 4). Section 5 provides conclusions and presents some limitations of our research.

2. Theoretical background

2.1. Advanced manufacturing technologies and industry 4.0

Recent developments in computer science and in information and communication technologies have rapidly penetrated in manufacturing operations and management, causing spectacular improvements in technology adopters' performance indicators. The integrated effects of digital transformation in manufacturing, driven by technology enablers such as the Internet of Things (IoT), cloud computing, artificial intelligence, big data analytics, virtualisation and augmented reality, are considered disruptive, hence new developments in manufacturing[1] are referred to as the fourth industrial revolution, or industry 4.0 for short (Kagermann et al., 2013; Manyika et al., 2013).

Industry 4.0 is a particular development stage of advanced manufacturing systems. It is often used as an umbrella term for a variety of digital enterprise technologies.[2] Some scholars refer to cyber-physical production systems as the epitome of the digital transformation of manufacturing (Chen, 2017; Monostori et al., 2016).[3] Cyber-physical

---

[1] The list of technologies and applications that are integral to industry 4.0 is longer, including, among others, robotic technologies and additive manufacturing (Lu, 2017). The collective term of industry 4.0, itself, undergoes continuous development, with rapidly emerging new enabling technologies (e.g. 5G networks, mobile edge computing – Cheng et al., 2018; Li et al., 2018), and better system infrastructures that are expected to allow for new IoT applications and new practices, such as Internet of Things-based integrated collaboration and cloud-based manufacturing (Lu and Cecil, 2016). In turn, new applications, practices and new business models pose new challenges and require even higher performance (capacity, speed reliability) by the enabling infrastructure, initiating thus a self-reinforcing, virtuous circle of development (Bi et al., 2014).

[2] Conversely, other scholars rather subscribe to the new-paradigm view of industry 4.0, maintaining that its revolutionary aspect cannot be restricted to new technology-driven enhanced performance parameters of manufacturing production. Gains in competitiveness will rather originate in an across-the-board transformation of business: in new ways of organising, integrating and controlling the value adding activities, in newly defined core competences and, occasionally, in new business models (Arnold et al., 2016; Porter and Heppelmann, 2014).

[3] Xu and Duan (2018) argue, however, that it is mistaken to equate industry 4.0 with cyber physical systems (CPS), first because CPS have important applications outside the purview of manufacturing, second, because there is more to industry 4.0 than manufacturing, since industry 4.0 solutions are used throughout the entire business cycle, not only in production.

production systems represent the hitherto most advanced stage of a gradual convergence between manufacturing technologies and information and communication technologies[4] (Bi et al., 2014; Chen, 2017; Monostori, 2015; Tao et al., 2017), enabling unprecedented vertical and horizontal connectedness (collaboration and information exchange) of business functions and activities within business units and across the global value chain.

Connectedness, or rather the integration and interoperability of information across production and production support activities and across production and business management constitute the very essence of digital transformation (Xu et al., 2018). Coupled with big data analytics, the integration of diverse functional areas permits achieving operational excellence and resource efficiency related goals, and offers new opportunities for value creation (Ardito et al., forthcoming).

The digital transformation of manufacturing fosters not only production quality and efficiency (Colledani et al., 2014) but also enhances firms' flexibility, agility and responsiveness to internal disturbances and to changes in the external environment (Babiceanu and Seker, 2016). Further, digital enterprise and shop-floor solutions allow for unprecedented transparency and thus enable the management of the ever-increasing economic, technological and social complexity of manufacturing and business activities (ElMaraghy et al., 2012).

A particularly important impact of advanced digital manufacturing technologies is that they codify and standardise some production-related technological and R&D activities that were previously regarded as specialised and tacit knowledge-intensive. Examples include production planning and scheduling, capacity and resource planning, production control, maintenance scheduling, process optimisation.

Cyber-physical production system embedded computational intelligence

- collects and analyses data about processes, products and production equipment (Xu and Duan, 2018)
- monitors equipment condition and the status of operating facilities (Bendre and Thool, 2016; Civerchia et al., 2017);
- controls production, manages workflows, automates tasks assignments and optimises processes (Xu et al., 2018)
- visualises the state of affairs, i.e. the developments in and the real-time status of a wide variety of production parameters (Babiceanu and Seker, 2016);
- develops predictions (e.g. about tool or asset degradation, or coating defects) that call for interventions (Xu and Duan, 2018);
- provides insights into root causes of production disturbances and suggests interventions (Zhong et al., 2016);
- visualises the outcome of the projected interventions, and enables virtual experimentation with alternative technologies, configurations, plans and schedules (Bi et al., 2014; Xu et al., 2014).

The evolution of manufacturing technologies and the digital transformation of manufacturing models are embedded in a broader process of *co-evolving* manufacturing products, processes, production systems, corporate strategies and capabilities, and social environment (Tao et al., 2017; Tolio et al., 2010). Empirical evidence indicates that investment in new technology results in the expected performance improvement if and only if technology investment is complemented by adequate organisational changes, changes in management techniques and an appropriate adaptation of firm strategy (Brynjolfsson and Hitt, 2000; Colledani et al., 2014; Lei et al., 1996; Tao et al., 2017). Moreover, upskilling and technology adopters' indigenous technological capability development are also indispensable (Autor et al., 2003; Fu et al., 2011; Lall, 1992; Morrison et al., 2008).

The next subsection addresses this latter item.

2.2. Production capability, technological capability, innovation and R&D capability

There is an extensive literature discussing technology adopters' indigenous technological capability accumulation, using the concepts of production capability, technological capability and innovation capability (Bell and Pavitt, 1993; Hobday and Rush, 2007; Kim, 1997; Lall, 1992; Radosevic and Yoruk, 2016, 2018).

Production capability is defined as the capability to operate a given level of technology with excellent operational efficiency. It represents the firm's routine-based ability to use existing technologies. Production capability is thus closely associated with the absorption and assimilation of technology (Cohen and Levinthal, 1990; Kim, 1997). In a dynamic perspective, production capability building refers to the accumulation of technology embodied in successive generations of increasingly advanced physical capital, together with the accumulation of the associated human capital required to operate the production system efficiently (Bell, 2009).

In a broader conceptualisation, production capability also encompasses the firm's ability to make minor efficiency improvements in the given production system, so as to move closer to the technological frontier and produce at world levels of efficiency or productivity (Radosevic and Yoruk, 2016, 2018).

This broader view of production capability highlights the lack of a sharp boundary between knowledge using and knowledge changing capabilities (Bell and Figueiredo, 2012; Lema et al., 2015; Radosevic and Yoruk, 2018). In this vein, technological capability refers to the capability to change (develop) products and processes *more significantly* than what routine production activities would require. Technological capability is manifested in relatively advanced engineering activities that adapt and improve processes or integrate new components into the production system[5] (Radosevic and Yoruk, 2016).

Conversely, innovation capability is defined as the ability to create new technology, design new features of products and processes, and/or develop patentable ideas (Bell and Figueiredo, 2012).

This conceptualisation of capability categories suggests that technological capability building is a continuous and cumulative process (Ariffin, 2010; Bell and Figueiredo, 2012). There are two points to make here. First, there is no automatic transition from production to innovation capability: the learning efforts the accumulation of innovation capabilities requires are different from those associated with the accumulation of production capability. Second, innovation capability cannot be restricted to its science-based R&D component. Design, engineering, testing and the associated management of change are also equally important components of innovation capability (Bell, 2009; Havas, 2014).

In a different, albeit equifinal approach, Radosevic and Yoruk's (2016, 2018) capability categories include R&D capability. In that model, R&D capability plays a twin role in technology upgrading. On one hand, it has an important role in absorbing knowledge generated elsewhere, i.e. in accumulating originally created understanding about given technologies. On the other hand, R&D capability also refers to the capability to undertake frontier technology activities.

The growing complexity of global companies' products, and

---

[4] Some preceding stages in the parallel development of and increasing interactions between manufacturing and information and communication technologies include computer numerical control, computer-aided design and computer aided manufacturing, computer-integrated manufacturing (where computers manage and control the entire manufacturing process), high-resolution manufacturing (that makes use of wireless communication, sensor networks and Internet of Things), and cloud manufacturing (Bi et al., 2014; Monostori, 2015). The organic link between AMT and industry 4.0 is also reflected by the successive labels of advanced manufacturing systems, introduced in the past half a century, including 'flexible', 'reconfigurable', 'computer-integrated', 'virtual' and 'grid' manufacturing systems, 'industrial product service system', 'cloud manufacturing' and so forth (cf. Tao et al., 2017).

[5] Some contributions refer to this latter kind of activity as one reflecting investment capability (e.g. Bell and Pavitt, 1993; Lall, 1992).

manufacturing and business systems (Chen, 2017; ElMaraghy et al., 2012) has made both roles of R&D capability become increasingly relevant for manufacturing subsidiaries in factory economies.

2.3. Drivers of capability upgrading at manufacturing subsidiaries

Increasing technological complexity is manifested among others in a higher-than-before number and increasingly diverse pieces of knowledge incorporated in products and production systems, and in a proliferation of interacting technical, computational, operational and functional domains in manufacturing and business systems (ElMaraghy et al., 2012). Complexity stimulates technological specialisation and requires changes in the organisation of technological activities, for example, it calls for R&D decentralisation and collaboration.

In this process, lead firms' role is transformed from one of a central knowledge creator into one of integrator of globally dispersed specialised knowledge stocks. Value chain orchestrators have become more inclined to offshoring and/or outsourcing advanced technological and R&D activities (Lewin et al., 2009; Linares-Navarro et al., 2014; Manning et al., 2008). These developments have been extensively discussed in the literature, for example in terms of the internationalisation of corporate R&D (e.g. Dunning and Lundan, 2009), intensification of open innovation (Chesbrough, 2003), organisational decomposition of innovation (Schmitz and Strambach, 2009) and organisation of corporate R&D in global R&D teams (Ghoshal and Bartlett, 1986; Von Zedtwitz et al., 2004).

The internationalisation and organisational decomposition of corporate R&D proved to be important drivers of technological capability upgrading in global companies' manufacturing subsidiaries located in factory economies (Contractor et al., 2010; Lema et al., 2015). Digital technologies, such as big data and product lifecycle management technologies, and web-based technological platforms have, in turn, further advanced the opening of corporate innovation processes (Del Vecchio et al., 2018; Lu and Cecil, 2016).

Firm-level capability upgrading is regarded in the literature as a cumulative, sequential process evolving across different stages (see review by Bell and Figueiredo, 2012). Analysed in an outcome-based approach, technological capability upgrading usually refers to the transition from production capability to technological capability, design, engineering and innovation capability (Fig. 1).

2.4. Modelling the impact of AMT on the upgrading of subsidiary capabilities

Our framework is aligned in many respects with the above-reviewed literature. In our framework, technological capability accumulation in manufacturing subsidiaries

a) is driven both by headquarters' (HQ) assignments and by entrepreneurial subsidiaries' continuous learning by doing (Birkinshaw and Hood, 1998);
b) is manifested first of all in technological activities closely connected with production (Lema et al., 2015);
c) materializes also in increasingly sophisticated indigenous R&D activities that are inputs to both absorption and innovation (Radosevic and Yoruk, 2016).

The main novelty in our framework is that in contrast to the received literature that considers the outcome of technological capability accumulation as a transition from one capability category to another, we interpret subsidiary technological and R&D capability accumulation as an evolutionary process, in which *the content and the nature of the individual capability categories become transformed.*

This evolutionary approach of analysing technological capability accumulation promises more precise insights in the impact of AMT deployment on the capabilities of manufacturing subsidiaries than the framework that conceptualises a sequential transition between capability categories.

The mechanism by which AMT deployment engenders the accumulation of local technological and R&D capabilities, and triggers the transformation of the individual capability categories themselves, can be summarised as follows.

By standardising, digitising and partly automating previously tacit knowledge-intensive production-supporting technological activities, AMT are redefining the boundaries of capability categories. Selected production-supporting technological services become automated and embedded into in-line equipment. The technological capabilities necessary to perform these activities turn out partly obsolete or are at least transformed and integrated into production capabilities. Conversely, the post-AMT-implementation activities requiring technological capability become deeper, more diversified and more knowledge-intensive, blurring the boundaries between technological capabilities and R&D capabilities.

This is represented in Fig. 2 by the fusion of part of technological capabilities in production capabilities. The modified shape of these capability categories refers to their changed content and composition.

Further, the integration of AMT into existing production systems often generates new technological problems that need to be addressed through subsidiaries' indigenous R&D (this will be detailed in Section 4.3). AMT solutions (e.g. virtual engineering solutions and simulation software) support and partly standardise production-related advanced R&D activities. This is represented in Fig. 2, as a merger of part of R&D capabilities, technological capabilities and production capabilities. Conversely, the changing nature (increased knowledge-intensity) of AMT-supported R&D is represented by a transformed shape of the capability category itself.

Altogether AMT both drive and enable the local accumulation of each of the three capability categories.

3. Research method and sample

An exploratory, qualitative approach, based on in-depth interviews and multiple-case analysis (Eisenhardt, 1989; Yin, 2003), was considered the most appropriate research method to examine the above propositions. As discussed below, in accordance with the guidelines of qualitative research (Glaser and Strauss, 1967), we scrutinised the patterns of capability upgrading through an indirect assessment method, by collecting information about changes in the nature and the skill-intensity of work in selected corporate functions.

3.1. Sample selection

The sample of companies interviewed was selected on the basis of two guiding principles. The first one was to choose ‘illuminative cases’ (see Patton (1990) about purposeful sampling). Accordingly, we selected companies with in-depth experience about AMT deployment.

Another criterion was to include diverse industries and user cases. For this sake, over and above selecting seven companies, representing four industries, automotive, machinery, electronics and metal casting (the representatives of this latter industry are suppliers of automotive and machinery firms),[6] referred to as technology users, we conducted interviews also with seven technology providers: industrial robot manufacturers, factory/process automation specialists, AMT-related engineering solutions services providers and system integration services providers.

These technology providers have a broad overview about market trends in Hungary with respect to factory automation, robotics, cyber-physical systems and other industry 4.0 solutions. The technology

---

[6] As technology user companies requested anonymity, their names will not be disclosed.

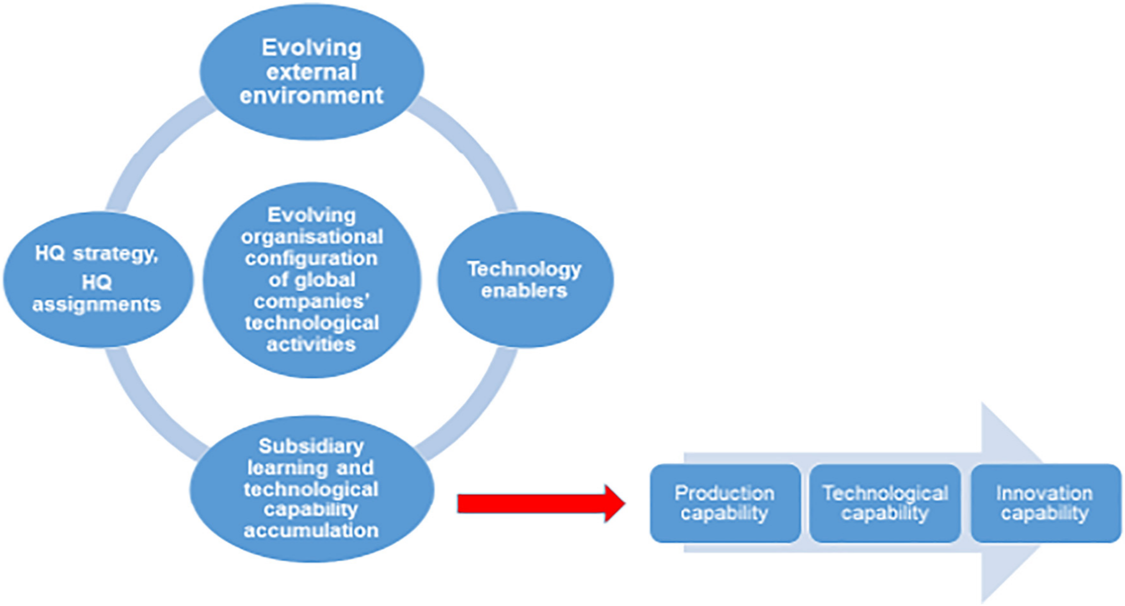

Fig. 1. Subsidiary technological capability accumulation.

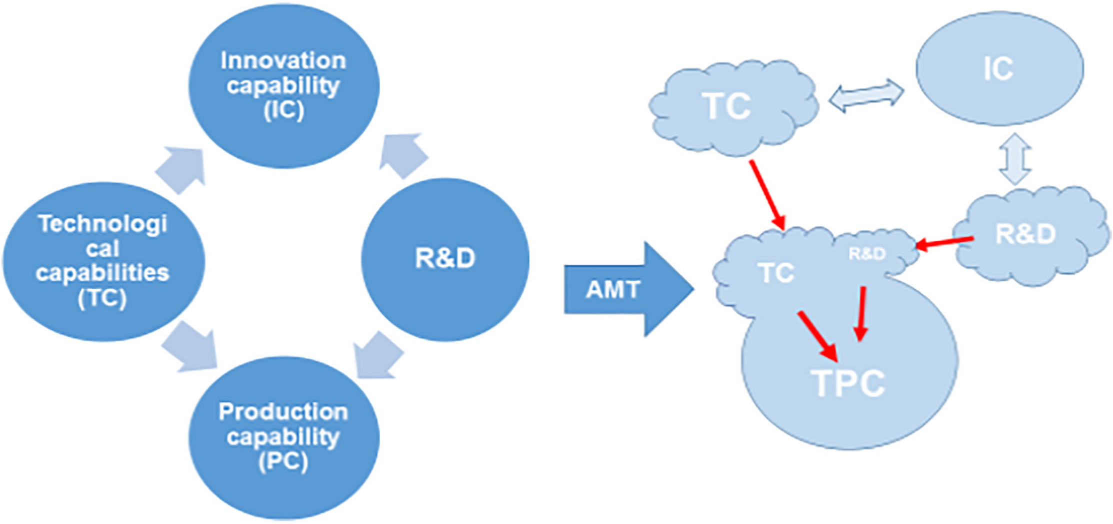

Fig. 2. The impact of AMT on subsidiary technological and R&D capability accumulation.
Note: TPC refers to the merger of production capability and part of technological capabilities.

providers interviewed recounted the cases of some of their own customers. They described the experiences of companies they have worked with when deploying cyber-physical solutions, robotic solutions or advanced decision-support systems. These narratives, although necessarily biased towards success stories, provided a deeper insight in the issues related to our research questions than what the limited sample size of user companies interviewed would have allowed for, and permitted to increase the size of the sample by five firms.[7]

In order to ensure insightful accounts about the subject of our research, the primary criterion applied when selecting the sample of technology users was the existence of AMT-related experience. All technology users in the sample utilise advanced factory automation, robotics, data extraction and traceability solutions. They have invested in digital production control, and quality control solutions. At the time of the interview, several companies in the sample were using or investing in data analytics and visualisation solutions (see more details in Section 4.1). Another purpose of ongoing investments was to increase vertical connectedness (e.g. connectedness between operations, inventory management and in-plant logistics), shift to paperless shop-floor management and to data-driven decision-making.

The main difference across sample companies was observed in terms of the development level of vertical connectedness, the number of functional activities supported by solutions allowing for data-driven

---

[7] Information about these latter five cases do not rely on interviews conducted with corporate executives but on the accounts of solution providers. This indirect evidence was triangulated through reviewing additional documents: business press articles about the companies in question, corporate websites and annual reports.

Table 3
Composition and basic features of the sample.

	Industry	Ownership	Size
TP			
ABB	KIBS, M	F	135
Fanuc	KIBS, M	F	24
Hepenix	KIBS	H	32
Cad-Terv	KIBS	H	33
Evopro	KIBS	H	104
Robolution	KIBS	H	12
NI Hungary	E, KIBS	F	1133
TU			
1	M	F	471
2	C	HU	224
3	A	F	925
TU			
4	C	F	898
5	M	F	1151
6	E	F	1349
7	A	F	592
CS			
1	E, A	F	3008
2	A	F	1544
3	M	F	572
4	C	H	735
5	C	H	817

TP = technology provider; TU = technology user (AMT adopter) manufacturing company, interviewed; CS = case study: information about customer (TU-firm) supplied by technology providers; A = automotive; M = machinery; C = casting; E = electronics; KIBS = knowledge-intensive business services; H = Hungarian-owned; F = foreign-owned; Size = number of employees in 2015.

decision-making and the development level of data analytics.[8]

Besides interviews with technology users and technology providers, complementary interviews have been conducted with two officials of the National Ministry of Economic Affairs, responsible for the coordination of Hungary's industry 4.0 strategy development under the auspices of the National Industry 4.0 Technology Platform, and with a representative of industry 4.0-related research, a researcher at the Institute for Computer Science and Control of the Hungarian Academy of Sciences.

Altogether, we conducted 16 interviews[9] between January and April 2017. Interviews were 45 to 60 min in length, and were conducted mainly with the chief executive officers, or with the technology officers of the companies.

The sample of companies our analysis relies on, consists of

- seven technology providers (AMT solution providers);
- seven technology users we have conducted interviews with;
- five technology users whose case studies were recounted by the technology providers interviewed.

Table 3 summarises the main characteristics of the sample.

3.2. *Data gathering and analysis*

In order to obtain rich and contextualised insights from our interviews, we used an interview protocol that contained open-ended questions about the impact of AMT adoption on the nature and the skill-intensity of work in selected corporate functions, such as production, process planning and control, maintenance and troubleshooting, quality control, product design and process development. These questions were introduced with general inquiries about the context and the motivations of AMT adoption, and about the specifics of the adopted technology. Finally we asked the managers interviewed whether they expect any additional upgrading opportunities to emerge as a beneficial side-effect of AMT deployment. Will AMT enhance subsidiaries' R&D mandate? Are additional R&D assignments anticipated? The list of the interview questions is presented in the Annex.

The focus of the questions in the core part of the interview protocol reflects that the connection between AMT deployment and the upgrading of subsidiary capabilities was identified through an indirect method of assessment (Achcaoucaou et al., 2014). Rather than asking our informants directly, to evaluate the impact of AMT on the individual capability categories, their descriptions of the changes in the nature and the skill-intensity of work in selected corporate functions helped us identify the *revealed* specifics of capability upgrading and its connection with AMT. As argued in Achcaoucaou et al. (2014), this indirect approach is expected to yield more accurate results than interview questions that ask respondents to evaluate subsidiary capabilities. Respondents reporting direct evidence of actions and processes usually provide more reliable (less biased) inputs than what they would when evaluating (changes in) their own capabilities.

We evaluated the transformation and the upgrading of capabilities by looking at signs of assimilation and/or indigenous establishment of new practices that result in improved cost effectiveness, enhanced labour productivity and/or a higher degree of operational excellence. We checked whether the identified changes in the ways work are done requires new types of capabilities, and collected information about the magnitude and the depth of learning and experience accumulation required to perform the transformed tasks.

Conversely, our interviews with technology providers were aimed to substantiate some of the connections between AMT deployment and subsidiary capability upgrading – that had been identified during the interviews conducted with technology user companies. Technology providers were first asked some general questions about

- market trends with respect to AMT;
- the features considered as the main novelty of AMT;
- their customers' motivations when investing in AMT;
- the main challenges and benefits related to AMT deployment;
- the main complementary investment requirements of the individual solutions.

Next, we inquired about technology providers' views about the impact of AMT on employment and the nature of work at their customers. In addition to substantiating the evidence obtained from interviews with technology users, technology providers' cases highlighted new connections that were, in turn, contrasted with findings from subsequent interviews. In this way, we applied a constant comparative method, in which each case helps to confirm or reject the insights emerging from previous cases (Glaser and Strauss, 1967).

In an effort to ensure validity, interview information was triangulated using additional information sources: corporate websites, business press articles, business reports and the companies' notes to the financial statement. External validity (Gibbert et al., 2008) was enhanced through complementary interviews (see Section 3.1).

The first draft of the paper was sent to all our informants for

---

[8] For example, the company (the Hungarian subsidiary) deemed the most advanced in terms of data analytics has developed a predictive and prescriptive maintenance solution, based on the data obtained throughout its production processes. This development level is referred to as ‘prescriptive analytics’ i.e. the system is capable to make predictions and recommend corrective actions. Conversely, the least developed company in the sample (in terms of utilising data analytics) has just moved from ‘no analytics’ (previously it only collected production data and transferred them to the parent company for analysis) to the level of ‘descriptive analytics’: due to the recently deployed analytics solution it became capable to visualise production status. Three technology users in the sample utilise analytics for ‘diagnostics’ (in the case of production disturbances) and two subsidiaries mentioned the ability of ‘prediction’ when describing the analytics solutions they utilised.

[9] The composition of the interviews is as follows: one interview per technology provider firm (seven interviews), one interview per technology user firm (seven interviews), one interview with two officials of the National Ministry of Economic Affairs (see below) and one interview with a representative of a research institute specialised in industry 4.0-related research.

approval and feedback. Their focused feedback helped us improve analytical rigour, and, at the same time, it enhanced the cross-sectional validity of the arguments.

4. Results

4.1. AMT transform the content of production capability

The implementation of AMT at the surveyed companies was initially manifested in the deployment of advanced industrial automation and/or robotics solutions that supported blue collar employees in selected difficult, dirty and dull activities, such as painting, welding, lifting, handling, manipulating, packaging, assembling, and so forth. It also concerned the integration of intelligent (cyber-physical) solutions in the production system, with the purpose of monitoring production and capturing production data. Our informants underlined that modern data extraction solutions have been embedded in production equipment for more than half a decade: tailor-made machinery is capable to extract and transfer data about various process parameters.

Later, additional processes have become automated, for example, production control processes (e.g. the Andon system), selected plant logistics processes, quality management and the testing of products. Another milestone marking the digital transformation of companies was the transition to paperless process management (e.g. in warehouse picking or in shop-floor operations).

The subsequent steps in firms' gradual digital transformation concerned the implementation of smart decision support systems. These latter support production planning and scheduling, optimise capacity utilisation, maintenance management and energy management. Our informants underlined that these systems and solutions are regarded as the real novelty of the industry 4.0 era: this is why the impact of AMT deployment is more than

- a high-speed, high-precision implementation of selected processing activities;
- data extraction on products, processes and the machinery itself;
- real-time access to production data.

As detailed below, notable changes in the nature of work and in the way activities are performed can be traced back to these latter solutions for information processing and sharing – and not to the deployment of robots.

The impact of the newly implemented automation and robotics solutions on blue-collar employees (number of employees, nature of work, required capabilities) was smaller than expected. Labour shortage has so far prevented the labour substitution effect of robotic solutions from becoming manifest.[10] While the implementation of advanced robotic systems has, indeed, replaced labour in selected activities, these employees have been redirected to perform easier tasks. As a representative of a robotic system provider formulated it:

> "*I have never received any complaints why we bring and install robots. In a foundry, for example, workers were quite happy when robots took over the task of pouring melted metal in the mould. Can you imagine the heat, the workload and the general work environment there? These workers were redirected to other non-automated material handling tasks, and continued working in a much less harsh environment.*"

The representative of a technology user company bluntly clarified why the projected employment effects of industry 4.0 can be regarded as a misconception.

> "*If I mention the buzzword of industry 4.0, everybody thinks of massive layoffs and unmanned factories. How do you think this can be conformed to our employing more than a thousand of workers? You should rather conceive the new manufacturing environment as a context where training is facilitated and physical work is aided by smart machinery. Smart machinery countervails human limitations. Skills – in every skill category – are augmented and not replaced by smart technology!*"

As for the capability requirements of working in a smart manufacturing environment (with embedded intelligence, visualisation and other labour enhancing techniques) our informants unanimously maintained that no major capability accumulation is required by factory workers.

> "*Learning to use the newly deployed interactive dashboards that visualise the state of production and display real-time production information proved to be much easier and quicker than expected! You know, when we say, 'operators are expected to understand and control the work process and the technology embodied in the machinery', this sounds intimidating. In reality, however, this refers to the application of already well-known practices in new contexts. Everybody is accustomed to touchscreens: people use the same technology in their smartphones.*"

> "*I would say, industry 4.0 is about upgraded shop-floor rather than about upgraded operators. In some cases, I would say, just the contrary happens: the skill content of operators' work is reduced, as they are supported by smart systems. Some systems visualise work instructions, other solutions provide a signal if operators pick a wrong piece or commit another mistake in the assembly process. The system itself excludes, or at least, reduces the possibility of defects. Not only mental, also physical workload is smaller. Remotely controlled robots have taken some of the dangerous and unhealthy manual tasks over. This allowed for a reconsideration of ergonomic issues: we reorganised tasks and designed new workflows.*"

> "*We switched to a paperless process management, and have automated documentation related tasks. Operators and technicians just swipe their badges and can access the list of work assignments, setup instructions, or other procedural information. Information relevant to their specific status is displayed on the touchscreen. They can also process information (perform production reporting). Employees in other functions use the same system: swiping their badges they can get access to details of current orders, track work in progress, inventory status or operational status. Signing in by swiping one's badge ensures that the displayed menu of topics be specific to the employee: they are not drowned in useless data. According to feedbacks, our transition to this smart way of working has indeed assisted work at all levels, and resulted in improved efficiency and speed.*"

In brief, our interview results confirmed a series of tests and pilot experiments described in the literature (surveyed by Yang and Plewe, 2016) that shop-floor systems are easy to use and work conditions in an AMT context are operator-friendly.

Other informants, however, underscored that the above-described deskilling effect of AMT is just one side of the coin. Blue-collar employees are, at the same time, encouraged to present their own process improvement ideas, and contribute to the solution of emerging problems and disturbances.

> "*We bring thousands of employee ideas to fruition! Most of them reduce cycle time by a couple of seconds, improve ergonomics or the accuracy of work. The impact of individual suggestions may be small, but together, they produce considerable savings.*"

Altogether, AMT implementation has considerably enhanced operational excellence and the productivity of physical processing and assembly activities.

Production capability is, however, not limited to the capability of performing manufacturing activities at "world levels of efficiency and productivity" (Radosevic and Yoruk, 2016, p. 19). Operational efficiency also encompasses the efficiency of technological and

---

[10] None of the sample companies reported any automation- or other smart solutions-triggered layoffs.

management activities that are directly related to production. These include capacity planning, production sequencing, production control, maintenance management, inventory management, energy management. These activities, just like quality management (understanding the root causes of defects and performing the necessary corrective actions) are hardly separable from production.

Contrary to blue-collar operators, employees in the above technical and management occupations have experienced more extensive changes in the ways of working. In these occupations, smart applications have automated documentation and reporting, and have drastically reduced the time requirement of tasks involving information search and analysis. Examples include planning and scheduling production, diagnosing production disturbances, analysing shop-floor problems, identifying bottlenecks, managing maintenance and optimising processes.

Also, job losses were more prevalent in job categories related to these activities.

> "*We have implemented a production scheduling system serving and optimising 150 production lines at a large machinery firm. Production scheduling was previously subject to intuitive albeit routine-based human planning, and was performed by 40 medium-skilled employees. System implementation has spectacularly improved both the productivity and the effectiveness of production scheduling. I admit, however, that the other side of the coin was the reduction of employment related to the given task from 40 to 2!*"

Drawing on the results of our interviews, we identified three mechanisms by which AMT augmented production capability.

First, since smart applications processed and analysed production data, provided insights, and suggested interventions, decisions affecting the management of production have become substantiated by data.

Finding answers to traditional technological questions becomes faster and more efficient with big data technologies (Xu and Duan, 2018). Quality control, for example, was traditionally based on inspection, sampling and meticulous scrutiny to find out the cause(s) of the identified defects. Root cause analysis necessitated several hours, or even days of work (information search, analysis, experimentation). With big data, every parameter of every product and every component of the production process is measured. Consequently, there is no need any more to conduct time-consuming research *to determine causality*: if *correlation* is identified (based on statistical estimation or pattern-matching)[11] root causes of defects or of system errors can be relatively reliably identified (by the smart systems).[12] Consequently, fault detection, troubleshooting and root-cause elimination have become quicker and more effective.

Second, AMT deployment resulted in unprecedented integration of firms' processes – not only throughout the production facilities but also across owners' globally dispersed production units, which, as illustrated by the following interview excerpt, is a key explanatory factor of improvement in operational performance.

> "*Now, we can get access to resources that were previously unimaginable. For example, if we encounter a problem in the production process and are unable to find out its reason, we can access the corporate cloud data: we can ask the analytics department to conduct a data mining exercise to identify similar cases historically — in Shanghai, in Mexico or anywhere in the world, where our owner has production subsidiaries. Additionally, there is a continuous flow of information across the dispersed production sites, documenting the technological problems that emerged somewhere in the world. The corrective actions undertaken to eliminate the given problem are also described and information shared. Every production unit has to check the relevance of every problem, take pre-emptive steps if the problem is found relevant. Of course, document these steps and make information available for other units across the global organisation.*"

Third, AMT automated several time-consuming production management activities, which allowed technicians and engineers to engage in more creative and higher value adding activities. Both routine management activities (e.g. preparing documentations) and more advanced ones, such as production planning and scheduling were automated. Consequently, technicians and engineers could dedicate more time to the analysis and identification of root causes of production disturbances. This latter activity, notably supported by in-line equipment embedded solutions that collect and analyse production-related big data to detect certain patterns of irregularities, has also become more efficient than before. Moreover, since embedded smart analytics solutions can predict the disturbances that are bound to emerge, for example, tool breakage or equipment failure, subsidiary engineers could take corrective actions and prevented the majority of production disturbances from materializing. Altogether, the reliability of production management-related technological activities has markedly improved and the time requirement of these activities was reduced.[13]

Altogether, AMT implementation

- enhanced operational excellence: reduced process and product defects;
- reduced overall costs through rationalising the use of resources;
- reduced asset downtime;
- reduced work in progress and inventory;
- improved inventory accuracy;
- reduced the cycle time of production and production support activities, including testing;
- improved overall productivity.

In brief, as a result of AMT adoption, *all components of production capability* have substantially improved at the surveyed companies.

A notable consequence of AMT adoption was the gradual fusion of selected production-related technological services into production. Manufacturing technologies are considered 'advanced' if a number of production-related technological services, such as monitoring and controlling the production process, collecting and analysing the related data, managing asset performance through developing predictions and suggesting corrective actions, performing production planning and scheduling and so forth, are performed, or at least significantly supported by in-line, digital technologies.

Thereby, AMT deployment has standardised and partly automated the functional tasks that were previously experience-based, tacit-knowledge-intensive, and required technological capabilities. These tasks have become integral parts of production. The concept of production capabilities has thus been extended to include some capabilities previously classified as 'technological'.

As a flip side of the same coin, the locus and the composition of subsidiary technological activities have also undergone noticeable changes, which elicited a transformation of the concept of technological capabilities.

4.2. Transformation of subsidiary technological capabilities

The foregoing arguments suggest that AMT deployment has a Janus face-like effect on subsidiary technological capabilities. On one hand, some production-related technological services become integrated in the cyber-physical production system. These previously tacit knowledge-intensive production-support activities become standardised,

---

[11] See Anderson (2008); Colledani et al. (2014) and Xu and Duan (2018) for details.

[12] This will of course not eliminate the application of traditional methods of analysis and experimentation, but will definitely enhance the effectiveness of traditional approaches (see Calude and Longo (2016) for a criticism of the 'end of theory'-hypothesis).

[13] One manager interviewed reported an average of 6% annual efficiency increase for the past half a decade. He underscored that production-related support activities accounted for the lion's share of this performance improvement.

automated and performed by in-line production technology. Consequently, the related capabilities become integral parts of production capability. Moreover, with automation, some capabilities, previously classified as technological capability, become obsolete.[14]

On the other hand, we found that the nature of subsidiary 'technological capabilities' has changed. Markedly supported by smart systems, subsidiary-level technological activities have deepened and have become more efficient. The activities classified now as requiring technological capabilities are related to

- troubleshooting, process improvement and optimisation;
- management of change in the production process;
- project implementation.

As outlined in the previous section, subsidiary engineers and technicians dedicate part of their working time to the analysis of production disturbances and to the design of corrective actions. Production disturbances are, however, defined in the broadest possible sense, including not only equipment failure, tool degradation, or quality problems. They include underutilised (idle) equipment, production bottlenecks, long cycle time, low yield, excessive unit energy consumption.

These problems call for process improvement and optimisation: activities that are going on relentlessly at manufacturing companies, even without problems and disturbances. Process optimisation is supported by advanced solutions, such as energy management software (optimisation of energy use), and plant or process simulation software. The latter solutions offer a digital representation of factory or assembly line layout, allowing for virtual engineering. Virtual process engineering is applied for the optimisation of logistics flows and for the design and optimisation of assembly lines, workstations, and processes.

Upgraded technological capabilities were manifested in new engineering-related responsibilities, for example, in subsidiaries' taking on engineering for ramp-up, for new product introduction and/or for process and system reconfiguration. This required the mastering of new practices, such as virtual engineering, and software-supported simulation, for example, to redesign work cells or assembly lines. Local engineers experimented with alternative technological options so as to detect errors still in a virtual stage.

> "*The value added of our engineers is much higher than, say, it was ten years ago. This achievement is partly due to new assignments, partly to our greater involvement in the development activities of the Austrian technology centre, but mainly, to the enhanced efficiency of the engineering work. Our task is to design the serial production process, which requires huge local engineering work. This activity has been significantly enhanced by advanced technologies, such as simulations, virtual layout design, virtual commissioning and so forth.*"

Our informants highlighted an unexpected beneficial side-effect of technology adoption, namely that the computer-aided technologies validated and substantiated local initiatives aiming at incremental process improvement. If data, virtual tests and simulations substantiate locally decided interventions, the related risks are reduced. Hence, advanced technological activities can be more easily decentralised and delegated to subsidiary level. Subsidiary technological capability becomes thus *revealed* and further upgraded through learning by doing.

When speaking about the deepening of technological activities and capabilities, both technology users and technology providers underlined the importance of and the difficulties associated with project implementation. AMT deployment necessitated technology adopters' advanced *problem framing capability*, as adopting firms' IT and production specialists had to work closely together with technology providers. Adopting firms had to provide detailed process, product and task specifications, define the set of relevant data, parametrise the simulation models, estimate and calculate inputs, set tolerances and provide expertise in the virtual commissioning process. In brief, technology adopters had to build up sophisticated technological capabilities to participate in the tailoring of the provided solution(s) to their own needs.

Technological capabilities had to be accumulated also to overcome some problems that emerged during sample firms' transition to a relatively higher level of industry 4.0 maturity. When trying to integrate processes and functional layers, or simply make use of the collected data, e.g. by deploying smart decision support systems, the integration and harmonisation of heterogeneous forms of, often inconsistent data, collected from a variety of sources necessitated sizeable development efforts. Access to (and retention of) engineers capable to interpret data often proved more difficult than expected.

4.3. Subsidiaries' evolving R&D mandate

Interrogating our informants about the specifics and the evolution of AMT-related subsidiary-level R&D activities, the first finding that crystallised from the narratives was the gradual, albeit continuous evolution of local R&D responsibilities. The surveyed high-performing subsidiaries were expected to gradually undertake production-related engineering and process development activities. Subsidiary researchers have become involved in global R&D teams, and were increasingly engaged also in product development activities.

According to the accounts of our informants, the evolution of subsidiary R&D mandates was both driven and enabled by AMT.

AMT drive the multiplication of subsidiary R&D assignments mainly by accentuating the technological and contextual complexity of the production system.[15] According to Letmathe and Schinner (2017), technological complexity refers to product and process architectures encompassing multiple technologies, and linking a variety of systems, agents, databases, and/or devices. Contextual complexity refers to the fact that technology is supposed to support a large and diverse set interconnected tasks and business functions. The key word in these definitions is *interconnection* (of scientific disciplines, technologies, tasks and processes). Given the ever stronger interconnections among components of the production system, changes in one constituent (e.g. deployment of new machinery, changes in processes, product features, software and so forth) will spill over to and necessitate adjustments in other constituents. The necessary adjustments call for indigenous research, for product, process and/or organisational innovations, and/or innovations in the working methods.

On the empirical front, one conspicuous commonality of the interview findings was that AMT implementation is an R&D-intensive process. AMT deployment was in each case accompanied by technology providers' (e.g. robotic systems integrators, digital manufacturing

---

[14] An important message that crystallised from the accounts of our informants is that in conjunction with the evolution of manufacturing technologies, this kind of evolutionary change in technological capabilities continues, suggesting a looming obsolescence of additional, previously tacit knowledge-intensive technological capabilities. As a first step, some previously tacit knowledge-intensive activities related to production control were standardised and automated in cyber-physical production systems. These systems have thus become characterised by *self-controlling capability*. Next, the scheduling of production activities was standardised and automated, making the related technological capabilities obsolete. Cyber-physical production systems have thus exhibited not only *self-controlling* but also *self-organisation capability*. Future IoT systems with embedded artificial intelligence solutions will allow for *self-optimisation* and *self-adaptation*. These latter technologies are thus bound to standardise and partially automate some of the current advanced technological activities aiming at production planning, reconfiguration, and process optimisation. Consequently, part of the related capabilities will also be obsolete in the medium term.

[15] Contrary to intuition, there is no contradiction between AMT adding to the complexity of the production system and the claim that the digital transformation of manufacturing was a response to its increasing complexity. Even though AMT definitely add to the complexity of the production system, AMT solutions can effectively address complexity by enhancing operational transparency and turning data and information into knowledge that can substantiate decisions.

solution and product lifecycle management solution providers) R&D services. Technology providers analysed adopters' production systems and investigated the feasibility of automation. They prepared digitalisation plans defining where and how to integrate smart computing solutions in the production system. Technology providers' preparatory R&D activities were supplemented with adopters' own R&D, e.g. programming, system engineering and optimisation. Providers' R&D, joint R&D, and adopters' R&D activities proved equally indispensable for integrating the new solutions in the production system.

Technology deployment was never a one-off investment project with a clear-to-determine end date. System interdependencies triggered new technological problems, hence, AMT implementation always required subsidiary-level research and industrial engineering.

> "*We developed a remotely controlled laser welding solution for an automotive company that replaced the traditional spot welding of car doors. This involved some changes in the design of both the fixtures and the doors themselves. Solution deployment was preceded by robot motion planning and simulation exercises to detect possible collisions. Furthermore, the layout of the work cell had to be reconsidered: visibility obstacles [of the laser beam] eliminated. These latter tasks were solved by means of simulations. Finally, appropriate adjustments had to be made in measurement and testing.*"

Altogether, it can be concluded that absorption-related subsidiary-level technological activities *breed new technological problems,* the solution of which requires additional R&D efforts. AMT deployment is thus an important driver of R&D capability development.

AMT also *enable* the deepening of subsidiary-level R&D activities. A multitude of software applications simplify the design of products or components, support modelling and simulation tasks and radically reduce the time requirement of engineering for product development. Software applications standardise some components of the complex product development process, which fosters the delegation of additional R&D tasks to subsidiary level. A primary example of subsidiary-level, AMT-supported R&D undertakings is the simulation-based analysis of product parameters (geometry, material properties, such as crack resistance, surface wear, fatigue, thermal behaviour). Other examples include the design of components for new/upgraded products and the design of tools.

Although 3D visualisation and virtual simulation are among the most spectacular features of AMT application in R&D, our informants assigned far greater importance to the fact that AMT allow for unprecedented connectivity among geographically dispersed team members.

> "*Communication among development partners becomes much more efficient if we 'speak the same language': if we apply the same design and simulation software, and the same formats and standards. With the new product development software enabling 3D design, simulation and data management, the product concept can be immediately integrated into our system, without time-consuming interactions between HQ and our design department. We design the new product or component, and prepare all the related analyses and the necessary documentation. Since every unit uses the same software, engineers at HQ can read and store our results (for comparison with the subsequently proposed adjustments) without having to check them with their own methods. The software application itself ensures compliance with the company-specific standards. These functionalities allow for seamless communication and collaboration.*"

> "*We receive product specifications, and prepare a 3D design (this activity is supported by appropriate software). Then, we perform the necessary simulations (this is also software-supported), and prepare the calculations related to manufacturability (here we make use of another application within the software package). Compliance with company-specific (internal) standards is checked by another application. In turn, another application supports the design of the manufacturing process, and another is used for the generation of the quote. Next, the manufacturing software embedded in the CNC machinery 'imports' the 3D design file, and the prototype gets machined.*"

In summary, software applications create an *integrated development environment* across global companies' distributed R&D centres and manufacturing facilities. They enable collaborative work, and a seamless and coherent data exchange so that local engineers' digital solutions can be validated or improvement proposed by HQ. These solutions reduce the risks related to the offshoring of R&D tasks, and thus permit a more granular division of labour also with regard to complex R&D activities.[16]

As outlined by a solution provider interviewed, the implementation of an integrated product data management application at the Hungarian subsidiary of an agricultural engineering equipment company facilitated the collaboration of the Hungarian engineers with the engineers at the owner's development centres in North America, Asia and at the HQ in Germany. This intensified the evolution of the Hungarian subsidiary into a technological competence centre.

From subsidiary perspective, the implementation of digital technologies supporting R&D is not only a means enabling local subsidiaries' coping with HQs' assignment of increasingly advanced R&D tasks, but also an opportunity to demonstrate competences. AMT adoption enhances subsidiaries' R&D capability becoming *revealed*. AMT may trigger a virtuous circle starting with increasingly advanced assignments stimulating subsidiaries' additional learning by doing and R&D capability accumulation.

5. Conclusions

Investigating the impact of AMT on manufacturing subsidiary capabilities on the example of a sample of AMT-adopting manufacturing subsidiaries in Hungary, we found that the deployment of advanced manufacturing solutions classified under the umbrella term of industry 4.0 entailed a multifaceted transformation of the individual capability categories. The content and the nature of production capability and technological capability have become subject to rapid change. In contrast to previous eras, when changes in manufacturing actors' capabilities referred to the extension and deepening of existing capabilities and to the resulting transition from one capability category to another (from production capability to technological capability and to innovation capability), the diffusion of nowadays' AMT involved more complex transformations.

AMT have spectacularly improved all components of production capability, which can explain the so far sparse occurrence of backshoring. Furthermore, selected production related, previously tacit knowledge-intensive technological activities have been codified and are now performed by in-line technologies. Consequently, the related technological capabilities have become part of 'production capability'.

Conversely, subsidiary-level technological activities, including process development and the upgrading of the production system have become more knowledge- and R&D-intensive than before, requiring the accumulation of advanced process development, programming, and problem framing capabilities.

The deployment of AMT fostered the accumulation of subsidiary R&D capabilities directly, since it increased the complexity of processing activities and induced new technological problems. Moreover, by enabling the global decentralisation of corporate technological and R&D activities and supporting R&D collaboration, AMT promoted the accumulation of subsidiary R&D capabilities also indirectly.

In summary, AMT has augmented both core and support activities, and enabled subsidiary capabilities becoming revealed and further upgraded.

---

[16] Cf. Del Vecchio et al. (2018) about the ability of the Big Data framework to change the way companies organise their collaborative R&D activities and engage in open innovation.

The main limitations of our research are the small size of the sample and the biased sample selection of 'high-flying', successful companies operating in AMT-intensive industries. Moreover, as we concentrate on AMT-driven capability transformation, the paper suggests a more extensive digital transformation of the surveyed companies than what might be the case. Several respondents underlined that this transition is a long and gradual process, and that the given company had taken just the first steps on this road.

Altogether, our results are hard to generalise. Another limitation is the relative shortness of the surveyed time period. Further research and a considerable extension of the sample are needed to find out the extent to which the observed transformations are industry-specific, foreign ownership-specific, and whether the results apply only to top-performing subsidiaries. Further research might also reveal whether the diffusion of AMT could, indeed, result in a beyond-a-threshold deepening of subsidiary-level knowledge creation, i.e. whether knowledge-exploiting manufacturing subsidiaries can really turn into knowledge-creating entities within their owners' innovation ecosystems.

Acknowledgements

Research support by the European Trade Union Institute is gratefully acknowledged.

Annex. Interview protocol

General information

1. Please specify the nationality of the parent company: where is the headquarters located?
2. Please specify the main products of the company.
3. Please indicate the number of employees in 2015.

Motivations of adopting advanced manufacturing technologies (AMT)*

*AMT and industry 4.0 technologies are used interchangeably

1. What kind of 'industry 4.0' technologies/solutions have been deployed at your company, in the past half a decade?
2. What was the main motivation of investment (cost reduction, employment reduction, cost efficiency increase, productivity increase; lead time increase; better overview of the processes, more flexibility, operational excellence; environmental sustainability, etc.) Please specify the motivations in the case of each technological solution.

Experience with AMT deployment

1. Which features of the deployed solutions do you consider as the main novelty that illustrates the alleged revolutionary character of industry 4.0?
2. What were the main difficulties associated with technology deployment? How did your company address them?
3. Did the newly deployed technologies deliver? Did they produce the expected improvements? Please specify the impact of each newly deployed technological solution on performance.
4. In which field was the impact of the new solutions the most beneficial, and why? Please explain.
5. Were there any areas where unexpected beneficial effects have been observed?
6. Were there any activities where the impact of the new technology/solutions did not produce the expected results? What was the reason?

Impact of AMT deployment on employment and the nature of work

1. Did industry 4.0 technology deployment bring about layoffs at your company? If yes, in which functions?
2. How did overall corporate practices and the nature of work change as a result of the new technological solutions? Please provide detailed examples with respect to (1) production; (2) production management; (3) quality control; (4) maintenance and troubleshooting; (5) process and product engineering; (6) administration?
3. What were the new skills required in the above-listed functions?

Impact of AMT deployment on subsidiary responsibilities

1. Are there any new production responsibilities or any other new tasks/activities that were allocated to your company just because the recently deployed advanced manufacturing technologies have permitted to perform these activities? Can you specify details?
2. Based on the recently acquired solutions, do you expect to gain any (new) R&D responsibilities?

References

Achcaoucaou, F., Miravitlles, P., León-Darder, F., 2014. Knowledge sharing and subsidiary R&D mandate development: a matter of dual embeddedness. Int. Bus. Rev. 23 (1), 76–90.

Anderson, C., 2008. The end of theory: the data deluge makes the scientific method obsolete. Wired Mag. 16 (7)(Available at: http://www.uvm.edu/pdodds/files/papers/others/2008/anderson2008a.pdf).

Ardito, L., Messeni Petruzzelli, A., Panniello, U., Garavelli, A.C., 2018. Towards Industry 4.0: mapping digital technologies for supply chain management-marketing integration. Bus. Process. Manag. J (in press).

Ariffin, N., 2010. Internationalisation of technological innovative capabilities: levels, types and speed (learning rates) in the electronics industry in Malaysia. Int. J. Technol. Learn. Innov. Dev. 3 (4), 347–391.

Arnold, C., Kiel, D., Voigt, K.I., 2016. How the industrial internet of things changes business models in different manufacturing industries. Int. J. Innov. Manag. 20 (8). http://dx.doi.org/10.1142/S1363919616400156.

Autor, D.H., Levy, F., Murnane, R.J., 2003. The skill content of recent technological change: an empirical exploration. Q. J. Econ. 118 (4), 1279–1333.

Babiceanu, R.F., Seker, R., 2016. Big Data and virtualization for manufacturing cyber-physical systems: a survey of the current status and future outlook. Comput. Ind. 81, 128–137.

Baldwin, R., 2013. Global supply chains: why they emerged, why they matter, and where they are going. In: Elms, D.K., Low, P. (Eds.), Global Value Chains in a Changing World. Fung Global Institute, Nanyang Technology University and WTO, Geneva, pp. 13–60.

Bell, M., 2009. Innovation capabilities and directions of development. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/2457/Innovation%20Capabilities%20and%20Directions%20of%20Development.pdf?sequence=1 (Accessed: 10/04/2018).

Bell, M., Figueiredo, P.N., 2012. Innovation capability building and learning mechanisms in latecomer firms: recent empirical contributions and implications for research. Can. J. Dev. Stud. 33 (1), 14–40.

Bell, M., Pavitt, K., 1993. Technological accumulation and industrial growth: contrasts between developed and developing countries. Ind. Corp. Chang. 2 (2), 157–210.

Bendre, M.R., Thool, V.R., 2016. Analytics, challenges and applications in big data environment: a survey. J. Manag. Anal. 3 (3), 206–239.

Bi, Z., Xu, L., Wang, C., 2014. Internet of things for enterprise systems of modern manufacturing. IEEE Trans. Ind. Inf. 10 (2), 1537–1546.

Birkinshaw, J., Hood, N., 1998. Multinational subsidiary evolution: capability and charter change in foreign-owned subsidiary companies. Acad. Manag. Rev. 23 (4), 773–795.

Brynjolfsson, E., Hitt, L.M., 2000. Beyond computation: information technology, organizational transformation and business performance. J. Econ. Perspect. 14 (4), 23–48.

Calude, C.S., Longo, G., 2016. The deluge of spurious correlations in big data. Found. Sci. 1–18. http://dx.doi.org/10.1007/s10699-016-9489-4.

Chen, H., 2017. Theoretical foundations for cyber-physical systems: a literature review. J. Ind. Integr. Manag. 2 (03), 1750013.

Cheng, J., Chen, W., Tao, F., Lin, C.L., 2018. Industrial IoT in 5G environment towards smart manufacturing. J. Ind. Inf. Integr. 10, 10–19.

Chesbrough, H.W., 2003. Open Innovation: The New Imperative for Creating and Profiting From Technology. Harvard Business School Publishing, Cambridge, MA.

Civerchia, F., Bocchino, S., Salvadori, C., Rossi, E., Maggiani, L., Petracca, M., 2017. Industrial internet of things monitoring solution for advanced predictive maintenance applications. J. Ind. Inf. Integr. 7, 4–12.

Cohen, W.M., Levinthal, D., 1990. Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35 (1), 128–152.

Colledani, M., Tolio, T., Fischer, A., Iung, B., Lanza, G., Schmitt, R., Váncza, J., 2014. Design and management of manufacturing systems for production quality. CIRP Ann. Manuf. Technol. 63 (2), 773–796.

Contractor, F.J., Kumar, V., Kundu, S.K., Pedersen, T., 2010. Reconceptualizing the firm in a world of outsourcing and offshoring: the organizational and geographical relocation of high-value company functions. J. Manag. Stud. 47 (8), 1417–1433.

Cruickshank, M., 2016. Adidas returns to Germany with robotic manufacturing. In: The

Manufacturer, (25/05/20).

Del Vecchio, P., Di Minin, A., Petruzzelli, A.M., Panniello, U., Pirri, S., 2018. Big data for open innovation in SMEs and large corporations: trends, opportunities, and challenges. Creat. Innov. Manag. 27 (1), 6–22.

Dunning, J.H., Lundan, S.M., 2009. The internationalization of corporate R&D: a review of the evidence and some policy implications for home countries. Rev. Policy Res. 26 (1–2), 13–33.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14 (4), 532–550.

ElMaraghy, W., ElMaraghy, H., Tomiyama, T., Monostori, L., 2012. Complexity in engineering design and manufacturing. CIRP Ann. Manuf. Technol. 61 (2), 793–814.

European Reshoring Monitor, 2017. Production reshoring cases between 01/01/2015 and 28/02/2017. https://reshoring.eurofound.europa.eu/reshoring-cases?field_company_name_value=&field_reshored_business_function_target_id%5B%5D=304&field_reshoring_announcement_dat_value%5Bmin%5D%5Bdate%5D=01%2F01%2F2015&field_reshoring_announcement_dat_value%5Bmax%5D%5Bdate%5D=28%2F02%2F2017&=Apply (Accessed: 01/03/2017).

Fu, X., Pietrobelli, C., Soete, L., 2011. The role of foreign technology and indigenous innovation in the emerging economies: technological change and catching-up. World Dev. 39 (7), 1204–1212.

Ghoshal, S., Bartlett, C., 1986. Tap your subsidiaries for global reach. Harv. Bus. Rev. 64 (6), 87–94.

Gibbert, M., Ruigrok, W., Wicki, B., 2008. Research notes and commentaries what passes as a rigorous case study. Strateg. Manag. J. 29 (13), 1465–1474.

Glaser, B.G., Strauss, A., 1967. Discovery of Grounded Theory. Aldine Transaction, Chicago, IL.

Havas, A., 2014. Trapped by the high-tech myth: the need and chances for a new policy rationale. In: Hirsch-Kreinsen, H., Schwinge, I. (Eds.), Knowledge-intensive Entrepreneurship in Low-tech Industries. Edward Elgar, Cheltenham, pp. 193–217.

Hobday, M., Rush, H., 2007. Upgrading the technological capabilities of foreign transnational subsidiaries in developing countries: the case of electronics in Thailand. Res. Policy 36 (9), 1335–1356.

Inzelt, A., 2000. Foreign direct investment in R&D: skin-deep and soul-deep cooperation. Sci. Public Policy 27 (4), 241–251.

Ivarsson, I., Alvstam, C., Vahlne, J.E., 2017. Global technology development by colocating R&D and manufacturing: the case of Swedish manufacturing MNEs. Ind. Corp. Chang. 26 (1), 149–168.

Kagermann, H., Helbig, J., Hellinger, A., Wahlster, W., 2013. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry; Final Report of the Industrie 4.0 Working Group. Forschungsunion.

Kim, L., 1997. Imitation to Innovation: The Dynamics of Korea's Technological Learning. Harvard Business School Press.

Kinkel, S., 2014. Future and impact of backshoring—some conclusions from 15 years of research on German practices. J. Purch. Supply Manag. 20 (1), 63–65.

Kravtsova, V., Radosevic, S., 2012. Are systems of innovation in Eastern Europe efficient? Econ. Syst. 36 (1), 109–126.

Lall, S., 1992. Technological capabilities and industrialization. World Dev. 20 (2), 165–186.

Lei, D., Hitt, M.A., Goldhar, J.D., 1996. Advanced manufacturing technology: organizational design and strategic flexibility. Organ. Stud. 17 (3), 501–523.

Lema, R., Quadros, R., Schmitz, H., 2015. Reorganising global value chains and building innovation capabilities in Brazil and India. Res. Policy 44 (7), 1376–1386.

Letmathe, P., Schinner, M., 2017. Competence management in the age of cyber physical systems. In: Jeschke, S., Brecher, C., Song, H., Rawat, D.B. (Eds.), Industrial Internet of Things. Cybermanufacturing Systems. Springer International Publishing, Cham, Switzerland, pp. 595–614.

Lewin, A.Y., Massini, S., Peeters, C., 2009. Why are companies offshoring innovation? The emerging global race for talent. J. Int. Bus. Stud. 40 (6), 901–925.

Li, S., Da Xu, L., Zhao, S., 2018. 5G internet of things: a survey. J. Ind. Inf. Integr. 10, 1–9.

Linares-Navarro, E., Pedersen, T., Pla-Barber, J., 2014. Fine slicing of the value chain and offshoring of essential activities: empirical evidence from European multinationals. J. Bus. Econ. Manag. 15 (1), 111–134.

Lu, Y., 2017. Industry 4.0: a survey on technologies, applications and open research issues. J. Ind. Inf. Integr. 6, 1–10.

Lu, Y., Cecil, J., 2016. An Internet of Things (IoT)-based collaborative framework for advanced manufacturing. Int. J. Adv. Manuf. Technol. 84, 1141–1152.

Manning, S., Massini, S., Lewin, A.Y., 2008. A dynamic perspective on next-generation offshoring: the global sourcing of science and engineering talent. Acad. Manag. Perspect. 22 (3), 35–54.

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P., Marrs, A., 2013. Disruptive Technologies: Advances That Will Transform Life, Business, and the Global Economy. McKinsey Global Institute, San Francisco, CA.

Monostori, L., 2015. Cyber-physical production systems: roots from manufacturing science and technology. Automatisierungstechnik 63 (10), 766–776.

Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S., Reinhart, G., Sauer, O., Schuh, G., Sihn, W., Ueda, K., 2016. Cyber-physical systems in manufacturing. CIRP Ann. Manuf. Technol. 65 (2), 621–641.

Morrison, A., Pietrobelli, C., Rabellotti, R., 2008. Global value chains and technological capabilities: a framework to study learning and innovation in developing countries. Oxf. Dev. Stud. 36 (1), 39–58.

Narula, R., Guimón, J., 2010. The R&D activity of multinational enterprises in peripheral economies: evidence from the EU new member states. In: UNU MERIT Working Papers, No. 48. United Nations University, Maastricht.

Patton, M.Q., 1990. Qualitative Evaluation and Research Methods. Sage Publications, Newbury Park, CA.

Pisano, G.P., Shih, W.C., 2012. Does America really need manufacturing? Yes, when production is closely tied to innovation. Harv. Bus. Rev. 90 (3), 94–102.

Porter, M.E., Heppelmann, J.E., 2014. How smart, connected products are transforming competition. Harv. Bus. Rev. 92 (11), 64–88.

Radosevic, S., Yoruk, E., 2016. Why do we need a theory and metrics of technology upgrading? Asian J. Technol. Innov. 24 (sup1), 8–32.

Radosevic, S., Yoruk, E., 2018. Technology upgrading of middle income economies: a new approach and results. Technol. Forecast. Soc. Chang. 129, 56–75.

Schmitz, H., Strambach, S., 2009. The organisational decomposition of innovation and global distribution of innovative activities: insights and research agenda. Int. J. Technol. Learn. Innov. Dev. 2 (4), 231–249.

Tao, F., Cheng, Y., Zhang, L., Nee, A.Y., 2017. Advanced manufacturing systems: socialization characteristics and trends. J. Intell. Manuf. 28 (5), 1079–1094.

Tassey, G., 2014. Competing in advanced manufacturing: the need for improved growth models and policies. J. Econ. Perspect. 28 (1), 27–48.

Tolio, T., Ceglarek, D., ElMaraghy, H.A., Fischer, A., Hu, S.J., Laperrière, L., Newman, S.T., Váncza, J., 2010. SPECIES—co-evolution of products, processes and production systems. CIRP Ann. Manuf. Technol. 59 (2), 672–693.

Von Zedtwitz, M., Gassmann, O., Boutellier, R., 2004. Organizing global R&D: challenges and dilemmas. J. Int. Manag. 10 (1), 21–49.

Xu, L.D., Duan, L., 2018. Big data for cyber physical systems in industry 4.0: a survey. Enterp. Inf. Syst. 1–22. http://dx.doi.org/10.1080/17517575.2018.1442934. (in press).

Xu, L., He, W., Li, S., 2014. Internet of things in industries: a survey. IEEE Trans. Ind. Inf. 10 (4), 2233–2248.

Xu, L.D., Xu, E.L., Li, L., 2018. Industry 4.0: state of the art and future trends. Int. J. Prod. Res. 1–22. http://dx.doi.org/10.1080/00207543.2018.1444806. (in press).

Yang, X., Plewe, D.A., 2016. Assistance systems in manufacturing: a systematic review. In: Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future. Springer International Publishing, pp. 279–289.

Yin, R.K., 2003. Case Study Research: Design and Methods. Sage Publications, Thousand Oaks, CA.

Zhong, R.Y., Lan, S., Xu, C., Dai, Q., Huang, G.Q., 2016. Visualization of RFID-enabled shopfloor logistics Big Data in Cloud Manufacturing. Int. J. Adv. Manuf. Technol. 84 (1–4), 5–16.

Andrea Szalavetz, DSc, works as senior research fellow at the Institute of World Economics of the Hungarian Academy of Sciences (MTA KRTK). Her main research fields include the economics of innovation, industry 4.0 and global value chain issues. Recent papers include: Chronicle of a revolution foretold – Industry 4.0 technologies and manufacturing subsidiaries. Studies in International Economics, Special issue of Külgazdaság, 2(2), 2016; Upgrading and value capture in global value chains in Hungary: More complex than what the smile curve suggests. In: Szent-Iványi, B. (Ed.) (2017): Foreign direct investment in Central and Eastern Europe: Post-crisis perspectives. Palgrave Macmillan, pp. 127–150.