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DISCUSSION PAPER SERIES

IZA DP No. 12141

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ABSTRACT

The Past and Future of Manufacturing in Central and Eastern Europe: Ready for Industry 4.0?*

In this paper we determine the industry 4.0 (I4.0) readiness of eight Central and Eastern European countries (CEECs): Bulgaria, the Czech Republic, Lithuania, Hungary, Poland, Romania, the Slovak Republic and Slovenia. We outline the nature of manufacturing in the region, describe three distinct time periods of industrialization since 1990, and explain the nature of I4.0. Using measures reflecting three key dimensions of I4.0-readiness, namely technological, entrepreneurial and governance competencies, we find that the Czech Republic, Lithuania, Hungary and Slovenia are most I4.0-ready, and that Bulgaria, Slovakia, Romania and Poland are the least ready of the CEECs. We make a number of recommendations. All the countries in the region could do more to promote entrepreneurship; to diversify and grow manufacturing export markets through focused trade facilitation and competitive exchange rates; and to cooperate regionally on industrial policy - through for instance establishing a regional CEEC I4.0 Platform.

JEL Classification: O14, O25, O33, O52, P27

Keywords: industrialization, technology, manufacturing, innovation, entrepreneurship, Eastern and Central Europe, industry 4.0, industrial policy

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* A revised version of this discussion paper is forthcoming as a chapter in Industry 4.0 and Engineering for the Future, edited by Mohammad Dastbaz and Peter Cochrane and to be published by Springer.

1. Introduction

Technological innovations such as digital platforms, artificial intelligence (based on big data) and automation, additive manufacturing (3D-printing) and smart materials are in the process of disrupting the world economy. This disruption is already evident in manufacturing. Here a "new" industrial revolution (Marsh, 2012), a "second machine age" (Brynjolfsson and McAfee, 2015), or a "4th industrial revolution" (Schwab, 2016) has been diagnosed. The digitization and automation of manufacturing characterizes what is known as industry 4.0, from Germany's *industrie 4.0*[1]. Industry 4.0 technology enable firms to improve operational efficiency, productivity, time to market, customer satisfaction, and to reduce carbon emissions, waste, costs and down-time (see e.g. McKinsey Digital, 2015).

Industry 4.0 (I4.0) will have significantly implications for the global distribution of manufacturing activities, the nature of manufacturing, and the contribution of manufacturing to employment and productivity growth (Naudé, 2017). For instance, given the centrality of computers and data, locations with strong connectivity, ICT software and hardware, large availability of quality data and availability of highly-skilled labour, with vibrant entrepreneurial ecosystems will become even more desirable for manufacturing. In the era of I4.0 it is not low labour costs that will primarily attract and sustain manufacturing: it will be how amenable a location is for hosting manufacturing that can be automated and digitized. As such, countries and regions should ask themselves, how ready are they for industry 4.0?

One of the regions in the world that face an imperative to be ready for I4.0 is the eight Central and Eastern European Countries (CEEC8)[2] that have joined the EU in the early 2000s. By 2017 these eight countries were home to 98 million people with a combined GDP of US$ 2,7 trillion. When in the early 1990s these countries transitioned from socialism to the free market, they went through significant restructuring accompanied by shedding of jobs from uncompetitive Soviet-era industries. Eventually all the CEEC8 achieved relatively high economic growth rates and experienced a gradual reduction in the gap in per capita incomes with Western Europe. Manufacturing in particular recovered, mostly due to an inflow of FDI, much of it in the automotive sector, which was attracted by lower labour costs, good skills and improving local business conditions in the CEEC8. This offshoring, largely from West European countries, has been described as "invest east, export west". By 2017 the average contribution of manufacturing to these 8 countries' GDP was at 20 percent higher than the EU average of 15 percent.

If the region does not absorb and apply the technologies of I4.0, its international competitiveness may suffer. Its labour and local markets may not be attractive enough

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[1] The term 'Industrie 4.0' is said to have been coined by Henning Kagermann from the German Academy of Science and Engineering (The Economist, 2015).

[2] The eight who joined the EU were the Czech Republic, Hungary, Lithuania, Poland, the Slovak Republic and Slovenia (in 2004) and Bulgaria and Romania (in 2007). The Czech Republic, Hungary, Poland and Slovakia are also known the Visegrad countries (V4), see http://www.visegradgroup.eu.

to attract or maintain further manufacturing investment. In the Czech Republic a shortage of labour is already proving a constraint on manufacturing. Without adopting I4.0 the region could again experience deindustrialization as in the early 1990s.

In this paper our main objective is to determine how ready the CEEC8 is for I4.0. What we mean by readiness in this context is how possible it is, or will be, for manufacturing firms to identify, absorb and successfully apply the technologies and techniques that are characteristic of I4.0? A secondary objective is to trace the progress that the CEEC8 has made in terms of industrialization since the 1990s and to understand from this the nature of manufacturing in the region at present, including its vulnerabilities and strengths.

To determine how ready the countries are for I4.0 we use measures reflecting three key dimensions of I4.0-readiness*: technological, entrepreneurial and governance competencies*. We measure each on the country level using a broad array of variables and calculate a composite distance normalization index in order to rank the countries in terms of these three competencies *vis-a-vis* one another. To the best of our knowledge this is first time that such a fairly comprehensive approach has been used to determine the comparative readiness of a group of countries to I4.0.

The rest of the paper is structured as follows. We first outline the recent history (since 1990) of industrialization in the region (section 2). Then we discuss the nature of I4.0 in order to be able to identify adequate measures for the preparedness of countries (section 4) followed by an analysis and ranking of the preparedness of the CEEC8 (section 5). We find that the Czech Republic, Lithuania, Hungary and Slovenia are most I4.0-ready, and that Bulgaria, Slovakia, Romania and Poland are the least ready in the region. We make a number of recommendations (section 6), in particular we call for the countries to do more to (i) promote entrepreneurship; to (ii) diversify and grow manufacturing export markets through focused trade facilitation and competitive exchange rates; and to (iii) cooperate regionally on industrial policy - through for instance establishing a regional CEEC I.40 Platform. The final section (section 7) contains a summary and conclusions.

2. (De) and (Re) - Industrialization in the CEECs

2.1 Concepts

At the outset of this section it is necessary that we clarify what we mean by de-industrialization and re-industrialization. As in Tregenna (2011:5) we consider the terms industrialization, deindustrialization and reindustrialization to "refer here to changes in the share of the manufacturing[3] sector in GDP and/or employment".

[3] In national statistics, manufacturing is a subset of industrial activities, which also includes construction and energy. Manufacturing is at the heart of the industrial sector (see Szirmai, 2012) and as such the focus in this paper.

When a country industrializes, the share of manufacturing in GDP and/or employment in manufacturing will increase. Deindustrialization is a bit more complex concept and has also been the subject in of increasing scrutiny in the literature (e.g. Bernard et al., 2016; Rodrik, 2015a; Tregenna, 2013; Nickell et al., 2008; Kollmeyer, 2009). In this paper we follow Tregenna (2011) in considering *deindustrialization* as occurring only when the share of manufacturing in GDP *and* employment decline, in contrast with much of literature where only a decline in the share of employment is seen as "deindustrialization". As Tregenna (2011:15) explains:

> "The point is that a fall in the share of manufacturing employment that is mostly accounted for by falling labour- intensity of manufacturing (i.e. increasing labour-productivity of manufacturing) would not necessarily have a negative impact on growth…This is very different from the case where the fall in the share of manufacturing employment is associated primarily with a decline of the manufacturing sector as a share of GDP".

Reindustrialization can be defined by as taking place when the "share of industrial activity increases in regions (or countries) where it had been higher and declining before" (Wink et al., 2016:464). The discussion of reindustrialization in policy and scholarly circles in recent years has been heavily influenced by the debate surrounding the possibility of the reshoring (or backshoring) of manufacturing activities back from developing countries towards the USA (e.g. Sirkin et al., 2011) and the EU's recovery strategy after the 2008-2009 global financial crisis, which explicitly calls for reindustrialization (European Commission, 2014).

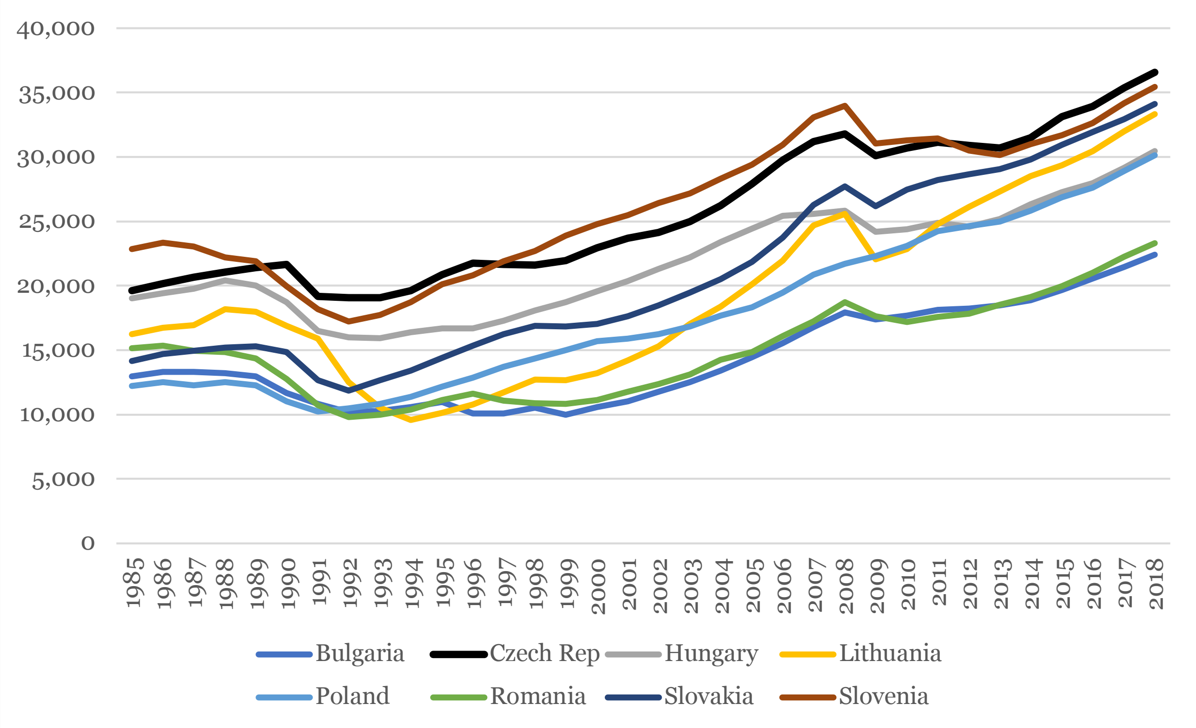
Reindustrialization can also be used to refer to the development of new types of manufacturing in a country, for instance when manufacturing shift from say being dominated by labor-intensive, low-skilled sectors towards high-skilled and more capital-intensive sectors (Lengyel et al., 2017). Here the new technologies driving I4.0 are seen to offer a scope for the renewal of manufacturing (Marsh, 2012; Wink et al., 2016). In this paper, all these notions of reindustrialization are relevant.

2.2 The Big Picture

The big picture as far as economic development and industrialization in the CEEC8 is concerned, is a positive one. The industrialization experience of the CEEC8, and more generally their development experience since the 1990s, following the end of the socialist period (1945 to 1989) has gone through three broad stages.

As *Fig. 1* shows, GDP per capita (in real terms) first declined until roughly 1995, then grew rapidly until the global financial crisis in 2008, experienced a short period of decline after which growth resumed, albeit at a slower tempo.

Fig. 1: GDP per capita in the CEEC8, 1985-2018



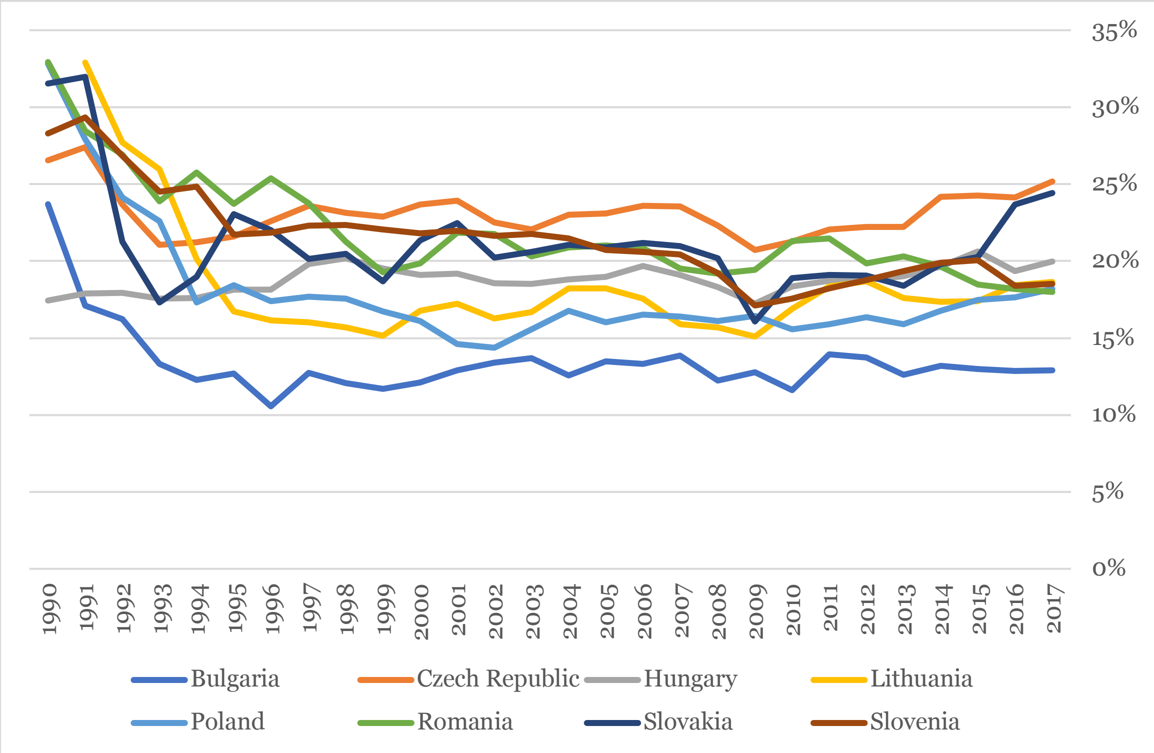
(Source: Authors' compilation based on the Total Economy Database of the Conference Board)

From *Fig. 1* three groups of CEEC8 countries can be distinguished. First, the higher-income countries, such as the Czech Republic, Slovenia, Slovakia and Lithuania; a middle group consisting of Hungary and Poland, and a lower-income group consisting of Bulgaria and Romania. *Table A1* in the Appendix contains a summary of GDP, GDP per capita, GDP growth between 1995 and 2017, and total population of these countries.

The distinctions evident in *Fig. 1* in terms of period of development and grouping in terms of level of development of countries are also reflected in the industrialization experiences of the countries, and as we will later show, their preparedness for I4.0.

Fig.2 shows the evolution of the share of manufacturing in GDP over the period 1990 to 2017, showing strong declines in the share of manufacturing in all countries up until around 1995, when there was a stabilization in the share, and some modest growth in some countries. Following the global financial crisis in 2008, there was a dip in the share of manufacturing in 2009 and 2010 in many countries, after which the share recovered in most countries, but not all. It is noticeable that in both post-crisis periods, i.e. just after 1990 and just after 2008, that there was more heterogeneity in terms of country experience in manufacturing changes than during the middle period between 1995 and 2008.

Fig. 2: Manufacturing valued added in the CEEC8 as percentage of GDP, 1990-2017



(Source: Authors' compilation based on UNIDO MVA Statistics)

Fig. 2 show that the region only experienced real deindustrialization in the period 1990 to roughly 1995, when *both* the share of manufacturing in GDP, as well as employment in manufacturing, contracted. After 1995, the overall trend in the share of manufacturing in GDP was positive.

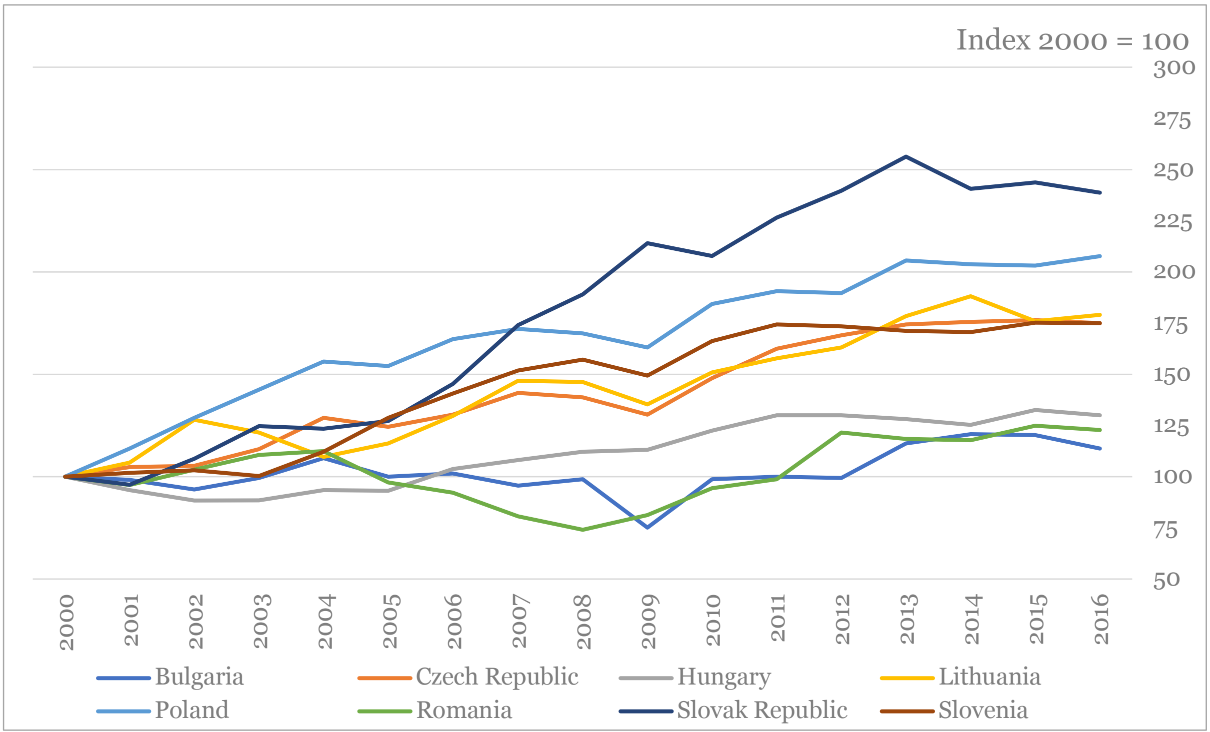
To further investigate the nature of industrialization over the period we consider the manufacturing production and manufacturing export structure's evolution over time. To do this, we use a crude ratio trend analysis to investigate how the relative value of exports (expressed in current US$ free-on-board values) relative to the value of manufacturing in GDP has changed over the period under investigation. In order to illuminate the change relative to the starting year we normalize the ratios to the year 2000 = 100. We plot the evolution of the manufactures export ratio to manufacturing value added in *Fig.* 3.

Over the period 2000-2016 Bulgaria and Romania exhibit very flat trends (small slopes) for the ratio of manufactures exports to manufacturing value added. Thus, their economic structure seems to have remained least affected by industrialization or de-industrialization (measured in terms of the slope of the ratio of manufactures exports to manufacturing value added over the period 2000 to 2016). The largest change over this period is exhibited by that of Slovakia.

Further comparing these outcomes with manufacturing as share of GDP and manufactures share of merchandise trade we find that there is a negative correlation between the relative (to 2000) share of manufacturing in GDP and manufactures share of merchandise trade. So, while the share of manufacturing in GDP for 5 of the 8 countries have slightly increased, it would seem that for Romania, Slovakia and Slovenia manufacturing's share of GDP has already started declining. Romania from 24.8 percent in 2011 down to 20.2 percent by 2016, Slovakia from a high of 22.5 percent in 2001 down to 20.4 percent by 2016.

A prominent feature observable in these trends over this period is the decline in international economic growth as well as trade due to the 2008-2009 global financial crisis. When evaluating the same indicators after this period (2010 to 2016), the trend in the ratio of manufactures exports to manufacturing value add for Hungary and Slovenia seems to have flattened while Bulgaria and Romania regained some traction. Over the more recent period Lithuania seems to have experienced the largest trend increase for this indicator. With the exception of Slovenia, all other CEEC8 countries have experienced and increased trend of manufactures exports (percentage of merchandise exports).

Fig. 3: Manufactures exports value as ratio of manufacturing value added for CEEC8, 2000-2016, normalized index (2000 = 100)



(Source: Authors' compilation based on World Bank Development Indicators Online)

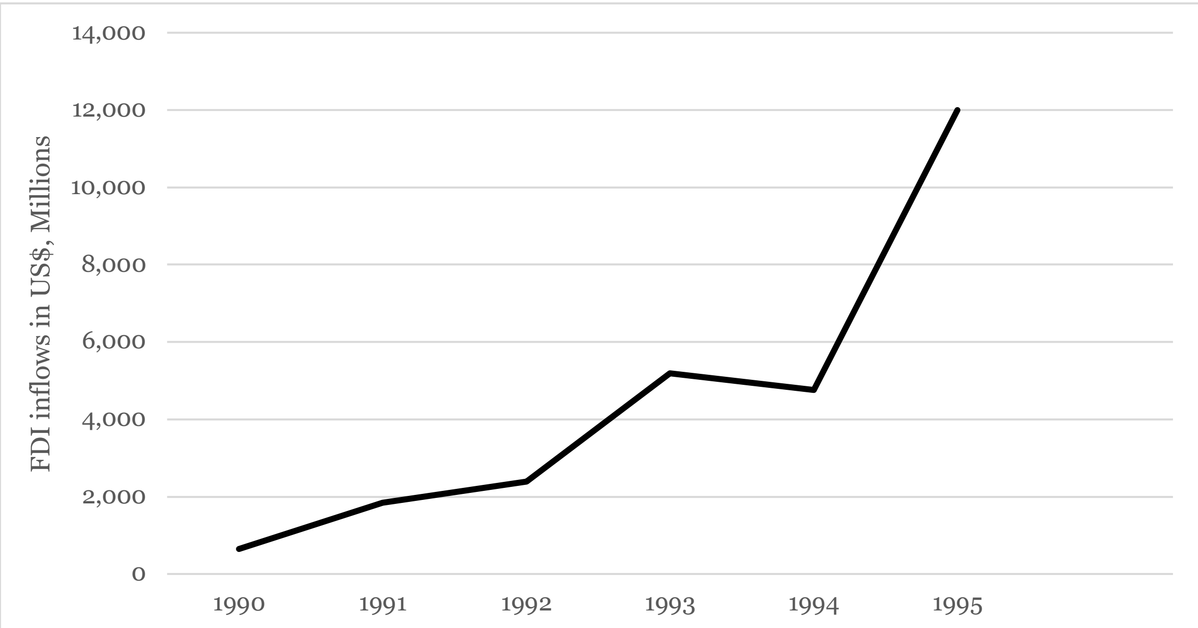
In addition, the structure of manufacturing changed significantly, suggesting a long period of reindustrialization, as we will explain in the following subsections, where we briefly describe the salient characteristics of these phases, including the upgrading of manufacturing.

2.3 *Post-Socialist De-Industrialization, 1990-1995*

The first post-socialist period of adjustment was between 1990-1995. The period 1990-1995 was characterized by significant deindustrialization, as the countries struggled to adjust to the post-socialist environment. It should be kept in mind that when the countries were part of the Soviet Bloc (1945- 1989) heavy (over-) industrial investment by the state saw traditional industries being created and significant employment in these heavy state-owned industries (Stojcić and Aralica, 2017). For example, by 1970 around 43 percent of all employment in Hungary was in industry (Lengyel et al., 2017). Moreover, during the Soviet Bloc era a technological gap widened between the CEECs and the West. The CEEC under Soviet isolation "never pioneered technological inventions…the Cold War made technology transfer impossible…the computer revolution stopped at the borders" (Berend, 2011:219).

After 1990 deindustrialization followed as these industries, most of whom were privatized, could not withstand the competitive pressures brought to bear by the fast growth in the inflow of FDI and foreign products (imports) as a result of greater trade openness (Lengyel et al., 2017). *Fig. 4* depicts the inflow of FDI (in nominal US$) into the CEEC8 over the period 1990 to 1995, showing its rapid growth.

Fig. 4: Foreign direct investment to the CEEC8, net inflows (current US$), 1990 to 1995



(Source: Authors' compilation based on data from the World Development Indicators online)

FDI brought in foreign technology and was relatively capital intensive and labor-saving; foreign takeover of local firms (in case of mergers and acquisitions) often led to downsizing domestic firms; and the higher competition pushed local competitors, who were less efficient, out of the market (see e.g. Onaran, 2008).

The extent of deindustrialization is apparent in the fact that between 1992 and 1995 more than 1,3 million jobs were lost in manufacturing in the eight CEECs, with the largest losses occurring in Romania and Hungary[4].

2.4 Transition and Reindustrialization, 1995-2008

The second period of modern industrialization in the CEECs was the period 1995 to roughly 2008. This period saw a consolidation of economic activities and the reindustrialization of the region, a reindustrialization that did not only involve growth in the absolute and relative contribution of manufacturing to GDP, but also in manufacturing employment, changes in the structure of manufacturing towards more high-tech manufacturing and relatively high growth in labour productivity (Filippetti and Peyrache, 2013). In addition, exports of manufactured goods increased significantly, and the share of high-skilled manufactured goods rose noticeably.

These gains were largely due to a continued inflow of FDI and an expansion of trade, in particular with the EU, to which the Czech Republic, Lithuania, Poland, Hungary, Slovenia and Slovakia acceded in 2004 and Bulgaria and Romania in 2007. FDI from and trade with the West were significant to help diffuse needed technologies from the West to the CEECs and help reduce the technology gap (Meriküll et al., 2013). This pattern of reindustrialization through acquisition of technology from Western Europe has been summed up in the saying "manufacture east, ship west".

An important fact to stress for purposes of this paper is that a major foreign investor in the region is Germany: by 2004, around 16 percent of employment in German firms' foreign affiliates were in the CEECs and between 1991 and 2004 around 68 percent of German FDI to CEECs went into the automotive[5] industry (Lipsey, 2006). Between 2006 and 2017 more than 1,800 German companies invested in 3,500 projects in the CEECs (Romei, 2017).

FDI inflows also helped to integrate the CEEC8 into global value chains. The extent of this integration is evident in that by 2011 CEEC8 countries such as Hungary, Slovakia and the Czech Republic were respectively the 2nd 3rd and 4th most integrated OECD members in terms of the foreign value added embodied in exports of manufactured goods. *Fig. 5* indicates that by 2011 the foreign value-added share of manufacturing exports exceeded 50 percent and exceeded the domestic value-added share in Hungary, Slovakia, and the Czech Republic, and was substantial in Slovenia and Poland. The bulk of manufacturing exports are towards the EU-15, and in particular Germany.

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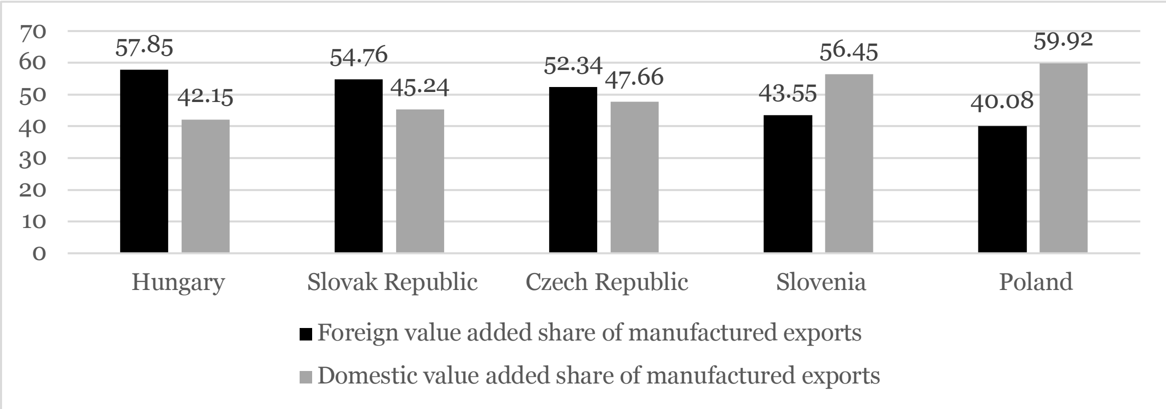
[4] Poland was the outlier: the country actually experienced a net gain in manufacturing employment over the period 1992 – 1995.

[5] French, Italian, Japanese, Korean, UK and USA automakers also followed suit, and as a result, a modern automotive industry, was created. Large MNE investors from the automotive sector include Peugeot, Fiat, Volkswagen, Opel, Audi, Renault, Hyundai, Mercedes Benz, Suzuki, Kia Motors, Jaguar, Ford, Volvo and General Motors.

Fig. 5: The Foreign and Domestic Valued Added Share of Manufactured Exports, percentage in 2011



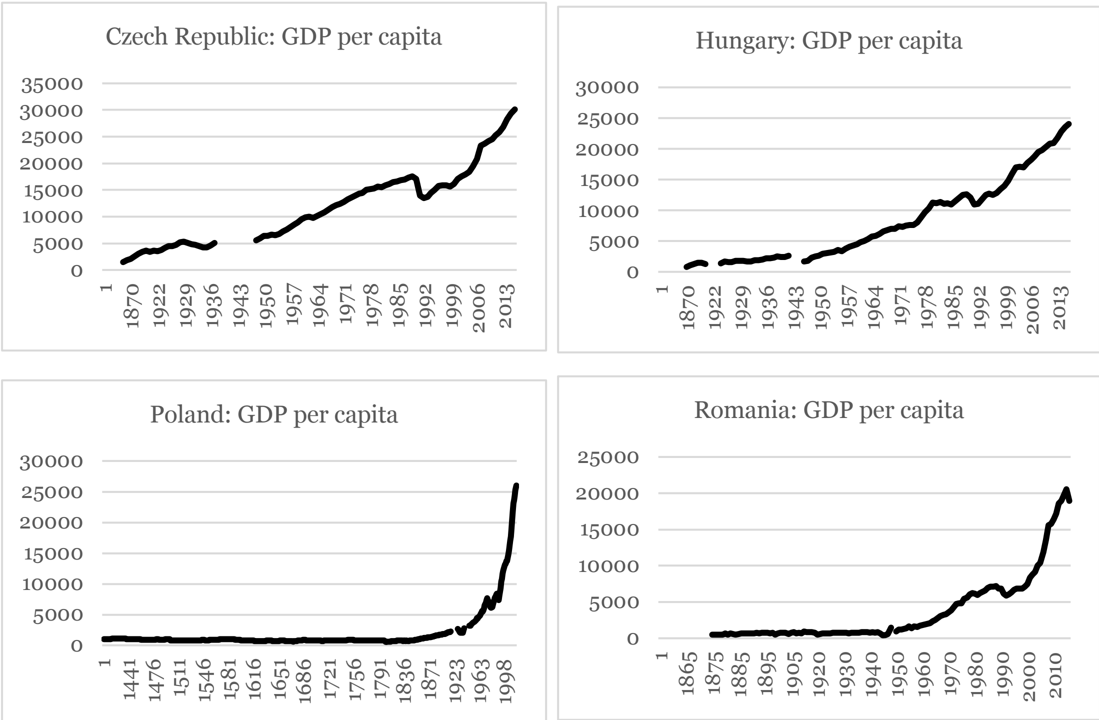
(Source: Authors' compilation based on data from OECD Trade in Value Added database (TiVA))

In addition to FDI, supportive investments in physical infrastructure, supported by EU Structural Funds[6], assisted in improving the environment for doing business.

As a result of all this investment, the accompanying increase in trade and openness, and improvements in the general environment for doing business, this period saw high growth. For instance, between 1995 and 2008 Polish GDP per capita doubled. In the words of Piatkowski (2013:2) Poland "*has just had probably the best 20 years in more than one thousand years of its history*". Not only Poland, but all of the CEEC8 achieved historically high growth rates. For the countries for which data allows, *Fig.6* depicts the almost exponential changes in per capita incomes experienced in the region since the late 1990s.

[6] The EU provides aid to former socialist members in the form of Structural Funds. Poland is currently the single largest recipient of these EU support, to receive the amount of €106 billion between 2014 and 2020 (Piatkowski, 2013).

Fig.6: Long-term growth in GDP per capita in selected CEECs, 1-2013



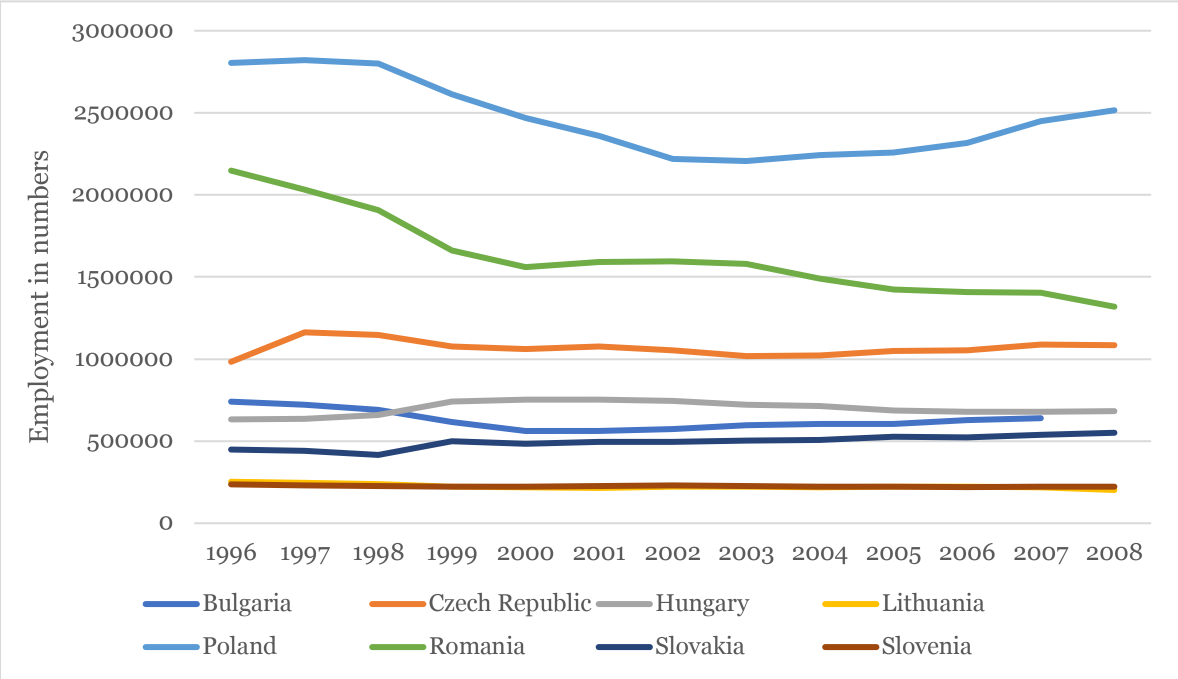
(Source: Authors' compilation based on data from the Maddison Project Database Version 2018)

The outcome of these significant economic changes was a complete transformation of the manufacturing sector in the CEEC8. For one, the decline in jobs was arrested, as *Fig.7* shows.

Fig. 7 shows moreover that in some countries, the stabilization in employment in manufacturing was rather quick after 1996, for instance in the Czech Republic, Slovakia and Hungary. In Poland, the stabilization and reversal of job losses in manufacturing occurred a bit later, around 2000, after which Poland started to see good growth in employment in manufacturing. Slovenia, Slovakia and Hungary saw stable employment in manufacturing during this period.

The only country where deindustrialization continued, was Romania, where not only the share of manufacturing in GDP declined, but also employment in manufacturing: the country lost around 829,000 jobs in manufacturing over the period.

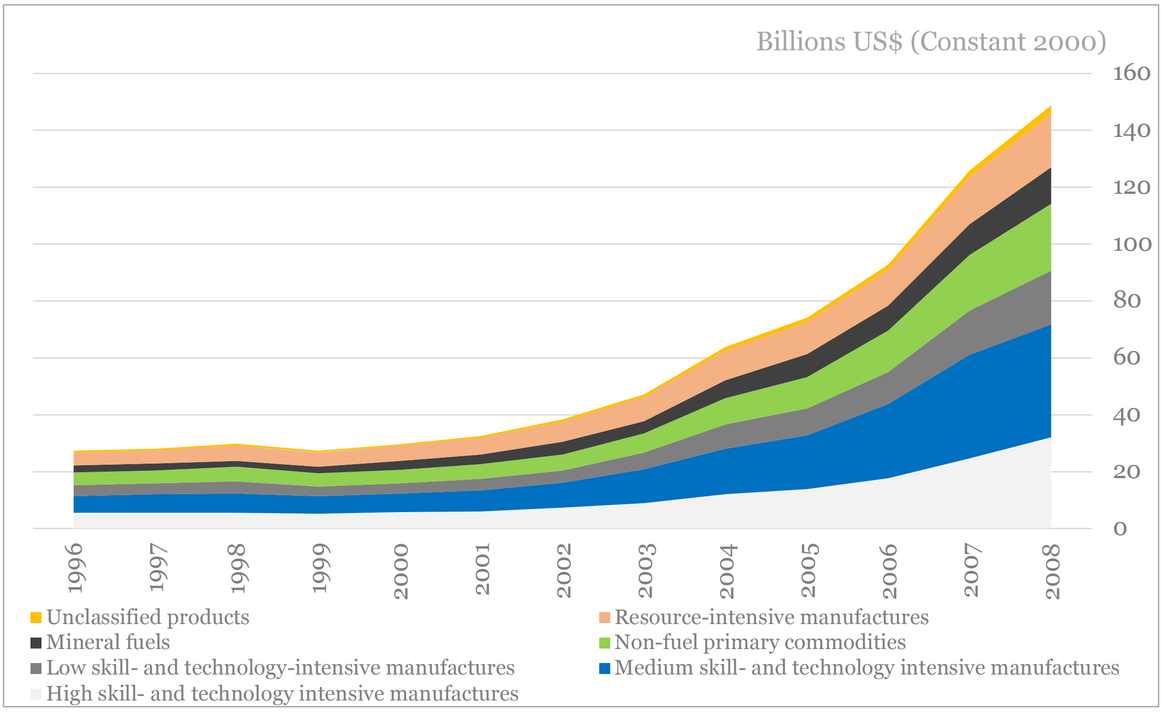
Fig. 7: Employment in manufacturing in the CEEC8, 1996-2008



(Source: Authors' compilation based on the wiiw industrial database 2010)

Finally, as for exports from the CEECs the reindustrialization period 1996 to 2008 saw exports growing fast, including manufactured exports, as was mentioned. In particular, a success of this period's industrialization is reflected in the fact that exports for the CEEC8 over the period 1996 to 2008 (see *Fig. 8*) demonstrates a gain in skill- and technology intensity composition of exports.

Fig. 8: Aggregated CEEC8 exports by skill- and technology intensity, 1996-2008[7]



(Source: Authors' compilation[8]*)*

As *Fig. 8* shows, the share of *medium skill- and technology intensive manufactured* exports (typically associated with the automotive sector) increased by 4.9 percentage points (from 21.7 percent in 1996 to 26.6 percent by 2008). High skill- and technology intensive manufactures exports also increased in share but less so by around 1.5 percentage points (from 20.1 percent to 21.6 percent). The largest decline in share is observed for resource-intensive manufactured exports at 4.3 percentage points followed by low skill- and technology-intensive manufactures exports at 1.0 percentage point.

2.5 Post-crisis Industrialization and the I4.0, 2009- present

The third period in the modern industrial development of the CEEC8 is from roughly 2009, the peak of the global financial crisis, to the present. It is characterized by a resurfacing of concerns with deindustrialization and reindustrialization, within the context of the 4th industrial revolution and I4.0.

It is a period that has seen the global financial crisis cause a reduction in economic activity, including trade and FDI. In the CEEC8 countries manufacturing growth

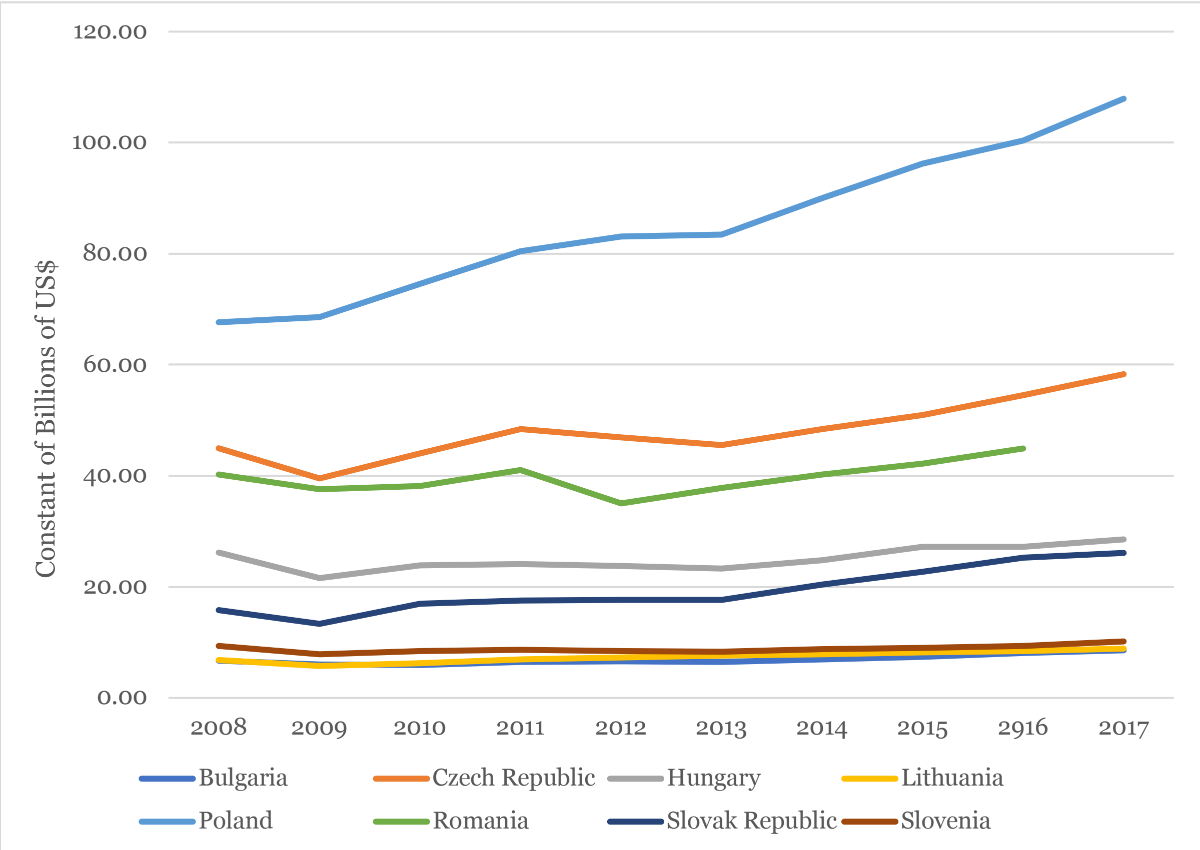
[7] Unfortunately, comparative trade data on a HS6 level is only available from 1995 onwards, so that we cannot provide comparable numbers for exports for the period immediately after 1990.

[8] The international trade data that we use is taken from the "Base Analytique du Commerce International (BACI)" data set which reconciles the UN COMTRADE database of CEPII (Centre d'Études Prospectives et d'Informations Internationales). See also Basu and Das (2011) and Basu (2011).

slowed down during and in the years immediately following the crisis, reflecting the slow of growth and demand in its most important trade partners, the EU and USA.

Fig. 9 depicts the real value of manufacturing output over the period. It can be seen that countries experienced a dip in manufacturing production between 2008 and 2009, but however not of the same magnitude. Worst affected were Hungary and Lithuania, who experienced declines in manufacturing of respectively 17 percent and 16 percent in 2009. Poland was the only country that did not experience a decline in manufacturing, although its growth in manufacturing output slowed down to 1,3 percent.

Fig. 9: Real manufacturing output in the CEEC8, 2008-2017 (billions of US$)



(Source: Authors' compilation based on World Bank Development Indicators Online)

Fig. 9 also show that the recovery in manufacturing output after the crisis was fairly swift, especially in Poland, the Czech Republic and Romania, although the latter two both saw a decline in growth between 2011 and 2012. By 2017, the largest manufacturing sectors in the CEEC8 were in Poland, the Czech Republic, Romania and Hungary.

While there was recovery in output after 2012 there was also in some countries important intra-manufacturing changes taking place. For instance, in the case of Hungary, Lengyel et al. (2017:1422) conclude that "on the basis of employment numbers and GVA data a dynamic re-industrialization process is hardly noticeable between 2009 and 2014; it is more a change of structure within manufacturing".

The structural change that they refer to is a reallocation of activities from low-skilled to medium and high-skilled manufacturing (with the exception of computer products): for instance, between 2009 and 2014 they found that employment in transport equipment manufacturing in Hungary increased by 19 percent and in machinery and equipment by 6 percent, while it declined in textile manufacturing by 4 percent. Consistent with these findings for Hungary, Stojcić and Aralica (2017:25) found that "across all countries an increase in the share of high technology intensive activities and improvements in productivity and export sophistication have taken place".

This period also saw further inter-sectoral shifts in the CEECs, in particular within the services sector where the participation of the CEECs in online labour markets became significant. By 2017 Romania had become the 9th largest supplier of online labour in the world, supplying especially online creative and multimedia work and software development[9].

While manufacturing output recovered in all CEECs after 2012 employment in manufacturing declined overall. However, this masks intra-manufacturing changes: generally, most job losses where in manufacturing of clothing and textiles, whilst motor vehicles and transport equipment manufacturing experienced job gains (Eurofound, 2016). These are also the sectors which according to Dachs et al. (2017) tend to be respectively low and high in terms of readiness to I4.0 technologies. In other words, *in recent times CEECs experienced job creation in sectors that may be I.40 ready, and job losses in sectors where I4.0 readiness are lower*.

One of the big threats to manufacturing in the CEECs that have emerged during this most recent period is that manufacturing activities could relocate as companies reconfigure their supply chains in light of new technologies associated with I4.0 as well as rising labour costs (Dachs et al., 2017; Ellram, 2013; Müller et al., 2017). This relocation involves both offshoring as well as reshoring.

Offshoring refers to the transfer of manufacturing activities from a home country to a host country, mostly through greenfield investment in a new plant, or through mergers and acquisitions. "Reshoring can be described as the reverse decision with respect to a previous offshoring process resulting in the transfer of activities to the home country (back-shoring) in a neighboring country (near-shoring) of the company (De Backer et al., 2016:8).

An increasing number of job losses in the CEEC8 manufacturing since 2009 have been blamed on offshoring of CEEC8 manufacturing activities: *between 2007 and 2016 the decrease in manufacturing jobs in the CEEC8 due to offshoring "increased by a factor of four"* from 4 percent to 15 percent according to Eurofound (2016:1). Around a third of offshoring activities from CEECs are towards other CEEC countries, in particular from countries where wages were higher, such as the Czech Republic, Hungary and Poland, to countries such as Slovakia, where wages were lower (Eurofound, 2016).

[9] See the Online Labour Index: https://ilabour.oii.ox.ac.uk/online-labour-index/

Around 12 percent is towards Western Europe, suggesting a relocation of manufacturing activities closer to (main) customers.

As far as reshoring is concerned, it seems to be accelerating, although the absolute magnitudes seem to be small or unknown yet (Eurofound, 2016). What is clearer is that German companies, amongst the most important investors in manufacturing in the CEEC8, have started to engage gradually more in reshoring activities. According to Müller et al. (2017) this is the outcome of Germany's *industrie 4.0* strategy (of 2011) which aims to "bring back production to Germany or turning to German suppliers" (p. 165).

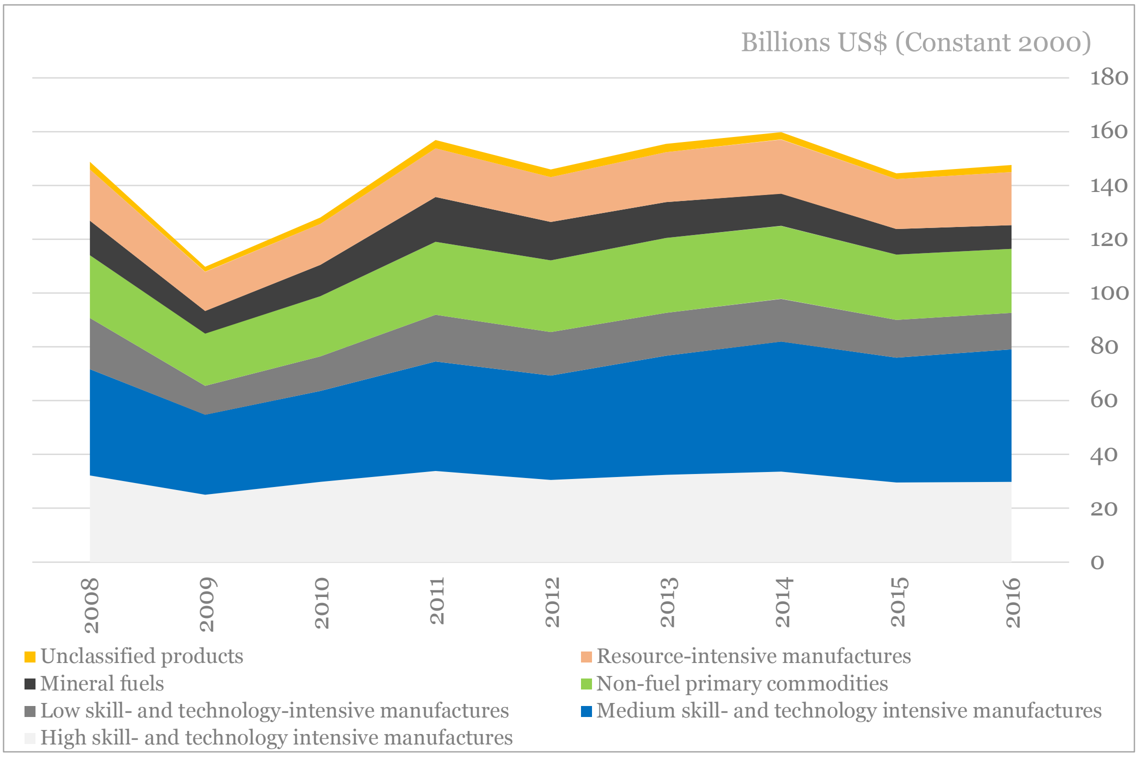
Such reshoring by German companies may be affecting the CEECs disproportionately: De Backer et al. (2016:11) reports that *up to 50 percent of all German reshoring cases in recent years consisted of reshoring activities from CEECs*. German companies seem increasingly to do this due to I4.0 motivations, such as to achieve greater operational flexibility and to achieve better control over the quality of manufacturing.

Eurofound (2016: 37) recounts in this regard the case of the German solar manufacturer Wolf, who reshored production back from the Czech Republic to Germany, stating that "robotics and creativity would compensate for the higher wage bill involved and that the production of solar collectors was increasingly reliant on the use of robots".

More evidence is provided by Dachs et al. (2017) who finds from a sample of 2,120 manufacturing firms from the European Manufacturing Survey 2015 that there is a positive association between the adoption of I4.0 technologies and the likelihood of these firms to reshore activities. De Backer et al. (2016) concludes based on similar considerations that digitization (i.e. industry 4.0) will discourage further offshoring to the CEEC and that the pressure is on reshoring of manufacturing back to Western Europe, especially in higher-tech sectors, due to the need for companies to be closer to where their main customer base is, and where research and development is being conducted: "advanced robotics will increasingly allow for substitution of labour…making offshoring to low labour cost regions less attractive". Increasing labour shortages in some CEEC8 countries may further reduce offshoring and stimulate reshoring (Szakacs, 2018).

Finally, we also investigate the aggregated (over members) exports for the CEEC8 over the period 2008 to 2016. This is depicted in *Fig. 10* which shows the sharp drop between 2008 and 2009 in exports from the CEEC8 during the global financial crisis. It also shows that export levels recovered by 2011, but from then on tended to be rather constant with no strong growth as in the previous period.

Fig. 10: Aggregated CEEC8 exports by skill- and technology intensity, 2008-2016



(Source: Authors' compilation)

Fig. 10 also shows that over the period 2008 to 2016, medium skill- and technology intensive manufactured exports (typically associated with the automotive sector) was the only grouping experiencing a further notable increase in share of export value (by 6.8 percentage points). Non-fuel primary commodities exports and resource-intensive manufactured exports experienced only a marginal increase (0.4 percentage points and 0.8 percentage points respectively) while the rest of the categories' relative shares decline over this period. As in previous periods, the largest decline is observed for low skill- and technology-intensive manufactures.

3. Industry 4.0: How Ready are the CEEC8?

In this section we analyze the readiness of the various CEECs for I4.0 by comparing and ranking them using a broad range of measures. To do so it is first necessary to identify the technologies associated with I4.0, and the conditions (infrastructure, skills and policies) that it requires for adoption, so that we can then obtain appropriate measures for each of the countries to reflect the extent to which they are utilizing and can utilize in the near future these new manufacturing technologies.

3.1 Key technologies of I4.0

I.40 is different from previous industrial revolutions in that its technologies are leading to an integration of the physical (material) and digital aspects of production and consumption. Key technologies are the Internet of Things (IoT), advanced materials, digital platforms, robotics, artificial intelligence, the Interface of Things and big data analytics (Naudé, 2017). Table 1 lists and explains these technologies.

In essence, digital transformation entails that digital and physical (or analog) technologies becomes integrated. Exponential declines in the cost of computing and exponential increases in computing power, data storage and bandwidth (Deloitte, 2018), together with the spread of sensors and development of better algorithms are facilitating this integration. It enables 3D-printing (additive manufacturing) – which is also facilitated by the development of new materials - and new modes of manufacturing such as the use of digital twins and digital shadows.

The digital technologies and new materials are discussed in Table 1. As far as the processes are concerned, I4.0 is allowing new production processes. For instance, in manufacturing these processes can refer to the "democratization" and "dematerialization" of production (Diamandis and Kotler, 2015).

The democratization of manufacturing is reflected in a growing "maker movement", which consist of small and micro-enterprises who combine 3D-printing with online e-commerce platforms (e.g. *Amazon Web Services*) to customize products and produce on demand, thus reducing the need for large production runs and economies of scale (Anderson, 2012; Graham, 2018)

The dematerialization of manufacturing is driven by the rise of digital manufacturing through use of Artificial Intelligence (AI) (e.g. in predictive maintenance) and the (Industrial) Internet of Things. For instance, by creating "digital twins" and using "digital shadows" design of products and factories, prototyping and experimentation can be done virtually. Products can be customized and produced (e.g. through additive manufacturing) only when demanded. Hence less materials are used in earlier stages of manufacturing, and less stock of final goods needs to be kept.

For the CEEC8 the I.40 offers the potential to remain competitive in the light of decreasing labor supply and rising wages. Labor supply is dropping due to low fertility, but also due to large outflows of workers, through migration to other EU countries, especially after 2011. Poland for instance saw more than 2 million workers, mostly young persons and potential workers, leave after 2004 (Piatkowski, 2013).

Table 1: Selected Key I4.0 Technologies

Technology	**Description and role in manufacturing**
(Industrial) Internet of Things	The Internet of Things refers to a system of devices, networks, software platforms and applications that makes possible for "sensors on physical objects to gather and shares information on the objects and their environment" (ECLAC, 2018:25). Applications are in optimization of production, predictive maintenance, the "serficivication" of manufacturing, tracking products, automated flows, customized production. Around 8,4 billion objects were connected to the IoT by 2017 (ECLAC, 2018).
Digital platforms	A digital platform is "a technology-enabled business model that creates value by facilitating exchange between two or more independent groups…built on a shared and interoperable infrastructure, fuelled by data and characterized by multi-stakeholder interactions" (ECLAC, 2018: 61). Applications are in online and digital trade, software-as-services, infrastructure-as-services, the on-demand economy, collaborative manufacturing and manufacturing design, customization, recruitment, and financing. The five most valued global firms in terms of market capitalization in 2017 were all platform firms, namely Apple, Amazon, Google, Microsoft and Facebook (ECLAC, 2018).
Advanced materials	"Chemicals and materials like lightweight, high-strength metals and high-performance alloys, advanced ceramics and composites, critical materials, bio-based polymers, and nanomaterials" (Deloitte, 2018, p. 32) Applications are in automotive and aviation manufacturing, sporting goods, wind turbine generators and batteries, building materials (e.g. coatings) and displays.
Robotics	"Machines or systems capable of accepting high-level mission-oriented commands and performing complex tasks in a semi-structured environment with minimal human intervention" (Deloitte, 2018, p.34) Applications are in assembly and packaging of products, including welding, painting, and loading; and in manufacturing of drones.
Artificial intelligence	"The theory and development of computer systems able to perform tasks that normally require human intelligence" (Deloitte, 2018: p. 36) Applications are in predictive maintenance, computer vision (for e.g. quality assurance of production), automated driving, personalizing consumption.
3D-printing	"An additive process of building objects, layer upon layer, from 3D model data" (Deloitte, 2018, p. 28). Applications are in automotive and aviation design, dental printing and medical implants. By 2014 already more than 11 percent of US manufacturers had "switched to volume production of 3-D printed parts" (Tuuli and Batten, 2015:3).
Interface of Things	The Interface of Things includes "virtual reality (VR) which creates a fully immersable digital environment that replaces the user's real-world environment; augmented reality (AR) which overlays digitally-created content into the user's real-world environment; mixed reality (MR) which seamlessly blends the user's real-world environment and digitally created context; wearables and gesture recognition technology that enables humans to communicate and interact with a machine" (Deloitte, 2018, p. 50). Applications are in virtual assembly manuals for factories, virtually designing factories and products, quality checks, instruction and training for manufacturing, and remote assistance.

(Source: based on Naudé, 2019)

Other CEEC countries also find a shortage of labour in manufacturing as a growing challenge, for instance manufacturing firms in the Czech Republic, Hungary and Slovakia that reported *labour shortages as a factor limiting production increased from an average of around 5 percent in 2010 to over 50 percent in 2017.* One response has been to hire more immigrant workers, in Poland for example the number of work permits issued to immigrant workers increased from around 25,000 in 2008 to over

200,000 in 2017[10]. Another response is to automate production. Thus, as reported by Szakacs (2018) "…here automation is a godsend…companies across Eastern Europe are ramping up investment in automation to cope with labour shortage".

3.2 How Ready are the CEEC8 for I.40?

In this section we compare and rank the CEEC8s based on a large number of measures that captures how they are faring in terms of technology capabilities, entrepreneurship and government ability with respect to the key challenges that I.40 poses. While there have been at least two I.40 "readiness indices" for countries[11] compiled in recent times as far as we are aware (by Compagnucci et al. 2017 and by Roland Berger, 2014) the approach in this paper is more comprehensive, by taking a more extensive approach towards the readiness of countries.

3.2.1 Approach

The approach is summarized in *Diagram 1*, which indicates that there are three broad dimensions of readiness to I4.0: i) technological competencies, ii) entrepreneurial and innovative competencies and iii) governance competencies. This reflects, as per the discussion in section 3.1 that digital and automation technologies are central in I4.0. For instance, countries that already have experience with industrial robots may be better suited to be able to leverage further automation.

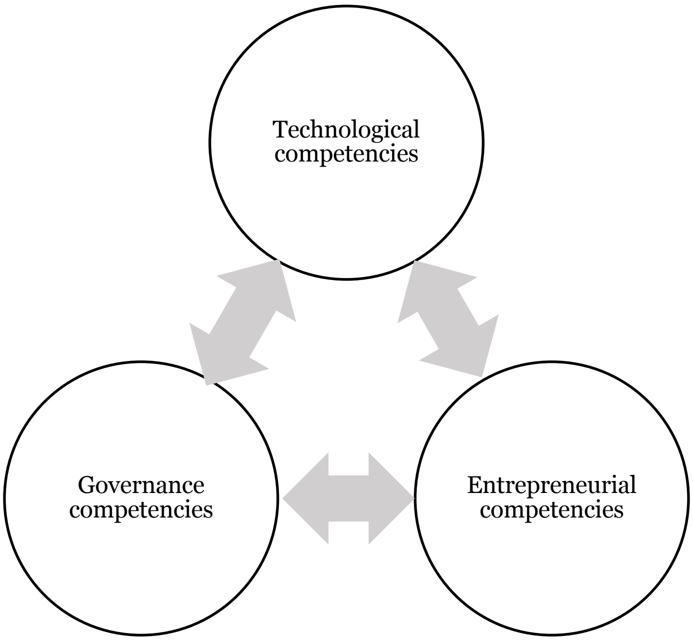
The three broad dimensions in *Diagram 1* also reflects that the ability to identify the opportunities in these technologies, such as for instance in providing better customer service and benefit from the circular and shared economy business models that becomes possible, and adapt these technologies to local circumstances, will be necessary for absorption and adoption.

Finally, technology adoption and entrepreneurship does not take place in a vacuum, but in a context wherein government policies and institutions can play a facilitating (or obstructive) role. If, as per the smart specialization strategies of the EU, which are also adopted in the CEECs, the triple-helix model of universities, companies and government need to work on the local level to develop high-tech manufacturing, then the three broad dimensions that are captured in measuring the readiness of countries, are appropriate.

[10] See: https://www.mpips.gov.pl/analizy-i-raporty/cudzoziemcy-pracujacy-w-polsce-statystyki/

[11] Dachs et al. (2017) compiles an I4.0 readiness index on a firm-level using data from the European Manufacturing Survey 2015, measuring readiness by the extent to which firms are using i) digital management systems, ii) wireless human-machine communication and iii) cyber-physical systems.

Diagram 1: Dimensions of I4.0 Readiness



Source: Authors

As *Diagram 1* suggests, the three dimensions of I4.0 readiness are not independent or separate: better technological capabilities may improve government competencies, and *vice versa*; similarly, countries with better entrepreneurial competencies may fare better in terms of technological competencies.

3.2.2 Technological competencies

Given that I4.0 is driven by new technologies, as summarized in *Table 1*, the first dimension to be considered is the technological ability of countries. To measure a country's technological ability for purposes of I4.0 one need measures reflecting to what extent countries are already using these technologies, and in particular one need to measure the extent to which the countries are digitizing.

In the first regard a wide range of such measures have been reported for the CEECs and other EU countries by Compagnucci et al. (2017) who also derived an *I-Com Industry 4.0 Index* for the preparedness of EU countries. They used **13** indicator variables that reflects the extent to which countries are adopting key technologies of I.40.

These thirteen indicator variables include the shares of manufacturing firms that use *radio frequency identification technologies* (RFID), *Enterprise Resource Management* (ERM) and *cloud-computing services, customer relations management* (CRM) systems, *big data analytics* (BDA), *supply-chain management* (SCM) processes. Their variables also include indicators of the physical and human capital to support manufacturing firms in the use of these technologies, such as the extent of *4G coverage*, the share of *STEM graduates*, the share of *ICT specialists* in total employment, the extent to which firms provide *ICT training* to their staff and the share of data workers in total employment.

As Compagnucci et al. (2017) compile these 13 variables into a single indicator summarizing a country's position, one need not here report the situation for each individual country but can use the indicator or index score for each of the CEEC8s. These are reported in *Table 2*, column 2.

For the EU 28 that average index score is 80 (the top scoring countries are Finland and the Netherlands). Only two CEEC8 countries achieve a higher than average score: *Lithuania* and *Slovenia* – two of the higher-income countries in the group. The other countries perform below-average and one CEEC8 country, Romania, one of the lower-income countries in the group, has the lowest score in the EU, i.e. is the least prepared country for I4.0 according to the Compagnucci et al. (2017) index.

For present purposes we add to the Compagnucci et al. (2017) index variables reflecting the state of the digital economy, security in the digital economy, and the potential ease for digital manufacturing and working with robots. In this regard, we use the *Digital Tax Index*, the IMD's *Digital Competitiveness Index,* the ITU's *Global Cybersecurity Index* (GCI) and the *International Federation for Robotics* (IFR) data on robotic use. All the indicators are shown in *Table 2*.

The *Digital Tax Index*[12] ranks countries based on how attractive they are from a taxation point of view for locating digital businesses. The average tax rate on digital businesses, taken from this index, is reported in column 3 of *Table 2*. It can be seen that this tax rate on digital business in CEEC8 countries such as Hungary, Lithuania, Romania, the Czech Republic, Slovenia and Bulgaria are lower than the average of 10,2 percent for the EU. Moreover, it is lower than the effective tax rate on traditional business (in 2017). More specifically, the effective tax rate on digital business is lowest in Hungary with -6,85 percent, which means that investments in digital businesses are basically subsidized (Compagnucci et al., 2017). The digital tax rates are highest in Slovakia.

We use the IMD's *Digital Competitiveness Index*[13] which aims to "assess the extent to which a country adopts and explores digital technologies leading to transformation in government practices, business models and society in general". In its 2018 ranking of 63 countries, the CEEC8 were all ranked in the bottom half, from 29th to 50th position. Their rankings are shown in column 4 of *Table 2*. Slovakia is the lowest ranked country – and also as was seen, the CEEC8 with the highest tax rate on digital business.

Given that digitalization is central to I4.0 the degree to which engaging in the digital world is secure from theft, fraud and corruption, in other words secure online property

[12] The effective average tax rate on digital business reflects the tax burden on digital business (Compagnucci et al., 2017)

[13] The EU publishes a related index, the *Digital Economy and Society Index* (DESI) for EU member states. There is a large overlap between components of these indices. We prefer the more globally oriented IMD index, as this perspective seems more relevant given that the digital economy is predominantly global in nature.

rights, is becoming of rising importance. This should also be seen against the rise in cybercrime in recent years – for instance it is estimated that in 2017 cybercrime cost the global economy US$ 600 billion (0,8 percent of global GDP) (Lewis, 2018). As such, countries aiming to make headway in I4.0 will need to make cybersecurity a priority. Cybersecurity measures need to go beyond the merely technical to include training, organization process changes, legal changes and improved cooperation. It is, as the ITU (2017:17) point out that "cybersecurity is an ecosystem where laws, organizations, skills, cooperation and technical implementation need to be in harmony to be most effective". The ITU's *Global Cybersecurity Index* (GCI) aims to measure a country's state of cybersecurity across the technical spectrum using **25** different indicators covering legal, organizational, capacity building and cooperation domains. We include the *Global Cybersecurity Index* scores for the CEEC8 to our analysis of their I4.0 readiness – these are contained in column 5 of Table 2.

According to the ITU (2017) none of the CEEC8 are leading in terms of their commitment to cybersecurity, although they all are "maturing" in their commitments. As can be seen from *Table 2* the country with the highest score in cybersecurity is Poland, followed by the Czech Republic and Romania. Slovenia and Slovakia do the least well in terms of this indicator. Globally, out of 164 countries, the CEEC8s fall in the mid-range in terms of their ranking on the index, between 33rd (Poland)and 83rd (Slovenia) position.

A fourth measure that we add to the I4.0 index of Compagnucci et al. (2017) is a measure of the extent to which manufacturing is already seeing automation, and workers are getting used to working with robots. We use the density of industrial robots per 1,000 of workers reported by the IFR and this is shown in column 6 of Table 2. It can be seen that the country with the highest density of industrial robots in the CEEC8s is Slovenia, followed by the Czech Republic and Slovakia. The least use of industrial robots is in Lithuania and Bulgaria.

Table 2 summarizes the all our indicators on the technological competencies of the CEEC8.

Table 2: I4.0 Readiness in the CEEC8: Technological Competencies

Country	I-Com Industry 4.0 Index Score 2017 [Highest = best]	Effective Average Tax Rate on Digital Business, 2017 (%) [Lowest = best]	Ranking on Digital Competitiveness Ranking, 2018 (of 63) [Lowest = best]	Global Cyber-security Index Score, 2017 [Highest = best]	Density of Industrial Robots in 2015 [Highest = best]	Technological Competencies Composite Normalized Score [Highest = best]
Bulgaria	64	9,52	43	0,579	0,07	0.65
Czech Republic	78	7,48	33	0,609	2,17	0.93
Hungary	68	-6,85	46	0,534	1,11	0.76
Lithuania	85	0,44	29	0,504	0,06	0.75
Poland	66	12,63	36	0,622	0,51	0.73
Romania	53	6,62	47	0,585	0,20	0.63
Slovakia	77	15,09	50	0,362	1,93	0.74
Slovenia	84	9,51	34	0,343	2,21	0.85

(Source: Authors' compilation based on data from PWC Digital Tax Index and IMD Digital Competitiveness Index; Compagnucci et al., 2017 and Filippetti and Peyrache, 2013:1016; and International Federation of Robotics data)

By normalizing the distance between scores for the 5 individual rankings and scores and taking an unweighted average of the results, the "*Technological Competencies Composite Normalized Score*" is calculated. Based on this approach as indicated in Table 2 the highest ranking CEEC8 countries (and hence those at more industry 4.0 ready based on this combination index from this data) are the Czech Republic, Slovenia and Hungary while the lowest ranking (the least industry 4.0 ready based on this approach) are Romania, Bulgaria and Poland.

3.2.3 Entrepreneurial and innovation competencies

Whether economies are I.40 ready depend not only on technical competencies and industrial sophistication, but also on how entrepreneurial and innovative the economic agents in a country are. This is because digital infrastructure, skills and know-how, and experience with manufacturing, do not necessarily translate into new products or new firms, or new processes being adopted and disseminated. Adopting and disseminating I4.0 technologies and approaches in the CEEC8 will also depend on innovative entrepreneurship.

Thus, in addition to the indicators in *Table 2* we consider the following indicators, contained in *Table 3*, as measures of entrepreneurial and innovative dynamism in the CEEC8, as additional indicators of how I4.0 ready the countries are.

For present purposes we do not consider measures of self-employment or small business prevalence as good measures of entrepreneurship. Rather, in the context of a

4th industrial revolution and its potential for creative destruction, we have more in mind the kind of Schumpeterian entrepreneurship as discussed in Henrekson and Sanandaji (2017).

Thus, we use five indicators to measure and rank the extent of innovative entrepreneurship in the CEEC8. These are contained in *Table 3*.

First, opportunity entrepreneurship, which is a measure of the share of early-stage entrepreneurship in a country that are actively pursuing an opportunity and thus excludes necessity or forced entrepreneurship. We use the *total entrepreneurial activity (TEA)* measure for opportunity from the Global Entrepreneurship Monitor (GEM). This measure is reported in column 2 of *Table 3*. It can be seen that Poland and the Czech Republic have the largest shares of opportunity entrepreneurs, and Bulgaria and Romania the smallest.

Second, we use the *number of billionaires per million of the population* as another measure of Schumpeterian entrepreneurship, following Henrekson and Sanandaji (2017). This measure is obtained from the *Forbes List of Billionaires* and shown in column 3 of *Table 3*. In 2018 there were according to Forbes 6 billionaires in the Czech Republic, 6 in Poland and 1 each in Hungary, Romania and Slovakia. In terms of population size, the Czech Republic stand out, with 0,57 billionaires per million – which is higher than the Western European average of 0,42 and also higher that Germany's average of 0,52. It is followed by Slovakia and Poland.

Table 3: I4.0 Readiness in the CEEC8: Entrepreneurship Competencies

Country	**Opportunity TEA** **(%, 2017)** [Highest = best]	**Billionaires per million people 2018** [Highest = best]	**Venture capital** **(% of GDP, 2017)** [Highest = best]	**Labor productivity growth (% p.a.)** **1993-2007** [Highest = best]	**Innovation Index Score (2017)** [Highest = best]	**Entrepreneurship and Innovation** **Composite Normalized Score** [Highest = best]
Bulgaria	1,0	-	0,037	3,4	0,229	0.45
Czech Republic	2,7	0,57	0,006	3,1	0,415	0.65
Hungary	2,2	0,10	0,054	3,8	0,359	0.58
Lithuania	2,4	-	0,079	5,8	0,332	0.67
Poland	3,7	0,16	0,036	4,9	0,270	0.63
Romania	1,2	0,05	0,037	4,4	0,157	0.40
Slovakia	1,3	0,18	0,014	4,8	0,323	0.47
Slovenia	2,4	-	0,006	2,8	0,465	0.44

(Source: Authors' compilation based on data from the EU Innovation Scoreboard, Global Entrepreneurship Monitor, World Bank Doing Business database, World Bank Development Indicators Online, Filippetti and Peyrache, 2013; Forbes List of the World's Billionaires, 2018)

Third, we use the extent of the availability and use of venture capital (VC) in a country as percentage of GDP. Venture Capital (VC) is seen as a good indicator for high-tech entrepreneurship, as this has become a primary means of funding high-tech start-ups (Bocken, 2015). This indicator is shown in column 4 of *Table 3*. Lithuania and Hungary stand out, where the VC as GDP share is the highest, with Slovenia and the Czech Republic the lowest.

Fourth, as an indicator of the ability of a country's entrepreneurs to turn technology into products and processes that can be applied in industry, we use measures of how labour productivity growth, measured as growth in output per worker. The more and better capital and technology a worker has access to, including "managerial" and other intangible technology (such as firm routines) the higher will labour productivity be. Hence, if lagging countries are closing the technological gap, through their entrepreneurs being able to turn ideas and inventions into innovations, this will reflect in growth in labour productivity.

Filippetti and Peyrache (2013) calculates labour productivity for the CEEC8 for the period 1993 to 2007 and this is shown in column 5 of *Table 3*. This shows that all CEEC in our sample achieved relatively high labour productivity growth rates from 1993 to 2007, indicating that they were closing the technological gap. The average for the eight CEECs over this period was 4,4 percent, which exceeded by a fair margin the average labour productivity growth in the old EU member states, which was on average 1,8 per cent over this period (although of course the old EU member states had almost double of the levels of labour productivity of the new EU member states by 2007). The countries with the highest labour productivity growth was amongst the higher and middle-income countries in the group, i.e. catch-up, were Lithuania, Poland, Slovakia and Hungary.

Finally, we report on the EU Innovation Scoreboard's *Innovation Index* the scores for the CEEC8 – see column 6 of *Table 3*. The EU's Innovation Index measures broadly the innovativeness of the economy using a wide variety of variables (a total of **27**), including *R&D expenditure, patent applications, exports of high-tech products, process innovations adopted by SMEs,* and others. Slovenia and the Czech Republic are the leaders in terms of innovation in the CEEC8, and Romania and Bulgaria have the lowest scores.

Again, we normalize the distance between scores for the 5 individual rankings and scores and take an unweighted average of the results, termed the "*Entrepreneurship Competencies Composite Normalized Score*". Based on this approach as indicated in *Table 3* the most I4.0-ready country measured on these dimensions is Lithuania, followed by the Czech Republic and Poland. The lowest relative scores are obtained by Romania, Slovenia and Bulgaria.

3.2.4 Governance competencies

The governance competencies that are most relevant to support I.40 would be those that support agile manufacturing, entrepreneurial start-ups, and process innovations. These types of competencies can be measured through five variables, as contained in *Table 4*. These are first, the country's leaderships' political management skills. The

Bertelsmann Governance Index ranks the countries "according to their leadership's political management performance between February 2015 and January 2017". We show this index for the CEEC8 in *Table 4*, column 2. Lithuania and the Czech Republic scores the highest in terms of this index, and Hungary and Bulgaria the lowest.

Second, we use the World Bank's *Government Effectiveness Index*, which "captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" (World Bank Governance Indicators, online). Here countries can score between -2.5 (very poor) and 2,5 (very good). In *Table 4*, column 3 we show this indicator for the present countries. It can be seen that Slovenia and the Czech Republic are ranked the best in terms of government effectiveness, and Romania and Bulgaria the worst.

Table 4: I4.0 Readiness in the CEEC8: Governance Competencies

Country	**Bertelsmann Governance Index 2017** [Highest = best]	**Government Effectiveness Score 2017** [Highest = best]	**Public support for Business R&D, % of GDP (20145)** [Highest = best]	**Rank on Doing Business Index (2018)** [Lowest = best]	**Citizens using public e-services (%, 2017)** [Highest = best]	**Governance Competencies Composite Normalized Score** [Highest = best]
Bulgaria	5,98	0,26	0,01	50	21	0.45
Czech Republic	7,03	1,02	0,08	30	46	0.80
Hungary	4,44	0,51	0,19	48	47	0.73
Lithuania	7,18	0,98	0,01	16	48	0.79
Poland	6,25	0,63	0,05	27	31	0.66
Romania	5,89	-0,17	0,03	45	9	0.41
Slovakia	6,70	0,81	0,02	39	47	0.67
Slovenia	6,78	1,17	0,07	37	50	0.78

(Source: Authors' compilation based on data from Eurostat, The World Bank and Bertelsmann Stiftung)

Third, we measure how the government supports innovative entrepreneurship. Here, we use to variables: the extent to which there is public support for business R&D (as percentage of GDP), and the ranking on the World Bank's *Doing Business Index*. *Table 4* shows that most public support for business R&D is in Hungary and the Czech Republic, with the least support in Lithuania and Bulgaria. In terms of the *Ease of Doing Business*, the most highly ranked country is Lithuania (in 16th place in the World Bank's Index) by quite margin over the other CEEC8. It is followed by Poland (27th rank) and the Czech Republic (30th rank). The lowest ranked in terms of doing business are Bulgaria (50th ranked) and Hungary (48th ranked).

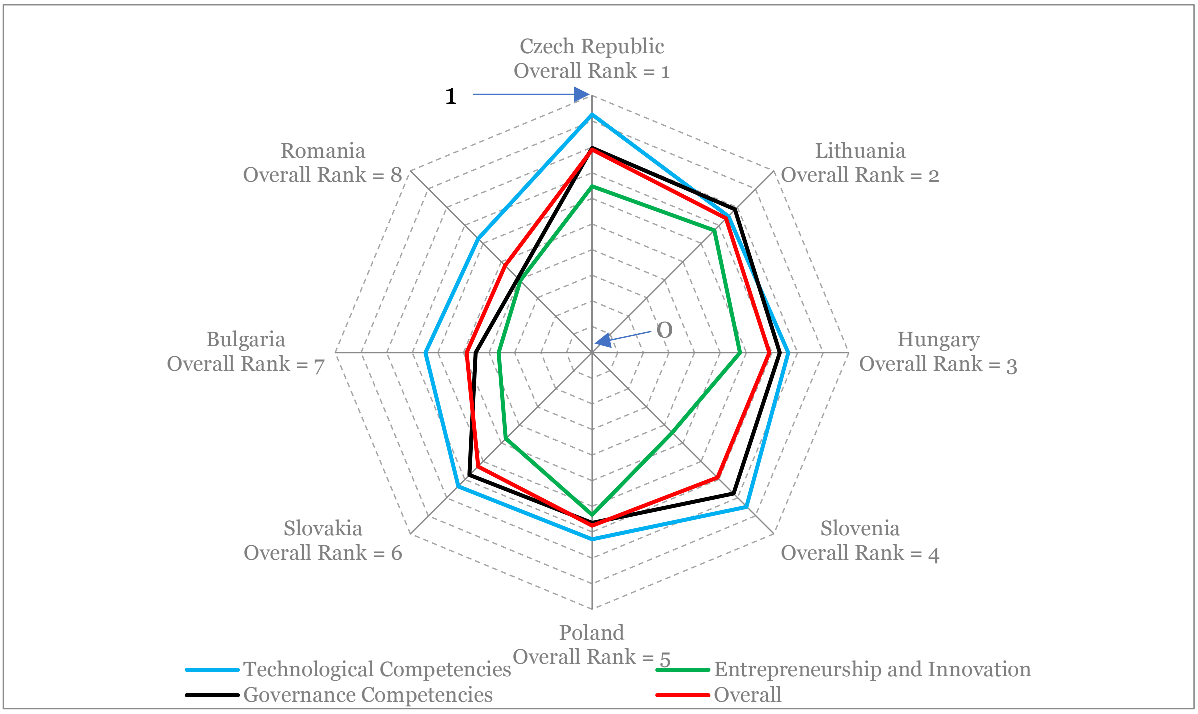
Finally, we measure how the government serves its customers (citizens) through offer digital services. Given the predominance of the digital economy in the I.40, it is also imperative that government be able to act and interact in the digital domain. We use Eurostat's measure from its community survey on the percentage of citizens using public e-services to interact with government. This is shown in column 6 of *Table 4*. Slovenia and Lithuania top the league and Romania and Bulgaria lag behind; the former quite substantially, with only 9 percent of citizens using public e-services.

Based on the same normalization approach we find that in terms of the "*Governance Competencies Composite Normalized Score*" the Czech Republic relatively performs best, followed by Lithuania and Slovenia. Romania, Bulgaria and Poland are in the lowest positions.

3.2.5 Total I4.0 Readiness Ranking

For each of the dimensions in Diagram 1 and the composite normalized score (between 0 and 1) based on the various indicators in Tables 2 to 4 in the previous sections, we ranked the CEEC8 countries, and took a simple average ranking to determine which of the CEEC8 are relatively to the others more or less ready for I.40. In *Fig. 11* we depict the outcomes for the CEEC8 in terms of the three dimensions, using a radar chart.

Fig. 11: I4.0 Readiness in the CEEC8 per dimension



(Source: Authors' compilation)

From *Fig.11* can be seen that the Czech Republic is ranked in first place, followed respectively by Lithuania, Hungary, Slovenia, Poland, Slovakia, Bulgaria and Romania in the 2nd to 8th positions.

The radar chart in *Fig.11* is useful to show how the various countries rank in terms of the three dimensions. Thus, for instance in Technological Competencies, the Czech Republic leads while in Governance Competencies, it is Lithuania that is ranked first. Similarly, all countries seem to be doing *least well in terms of Entrepreneurial Competencies,* especially Slovenia and Bulgaria. This indicates that there is no one recipe for all CEEC8 to improve their I4.0 readiness: all will have to focus on the three dimensions of I4.0 readiness, but different dimensions may have to be prioritized in different countries.

Overall, the conclusion is that the Czech Republic, Lithuania and Hungary are most I4.0-ready and that Bulgaria and Romania the least. This is good news for the Czech Republic, which also has the 2nd largest manufacturing sector (in terms of output) after Poland as well as the largest relative contribution of manufacturing to GDP in the region (see *Fig. 9*).

It is not such good news for especially Romania, which after Poland and the Czech Republic has the most substantial manufacturing sector in the region. Poland, with the largest manufacturing sector is overall ranked at position 5 only after much smaller manufacturing economies such as Lithuania and Hungary. Furthermore, a concern for Bulgaria is that as the EU already noted, it is falling behind in terms of digitizing its economy (as measured by the *EU's Digital Scoreboard* 2016) and hence may find itself diverging from the other CEEC8 in terms of industrialization.

The less-ready countries with substantial manufacturing have potentially much to lose through reshoring and offshoring, and declining international demand for their manufacturing production if they are not able to provide a more competitive environment for local I4.0. In the next section we discuss implications for industrial policies.

4. Industrial Policy Implications

The EU drafted an explicit strategic response (see EC, 2014) to the global financial crisis in order achieve significant reindustrialization of Europe by 2020[14]. Specifically, it aims very ambitiously to raise the average share of manufacturing in the EU's GDP from 15 percent to 20 percent by 2020 (Lengyel et al., 2017). I4.0 is seen as a means to this end.

As a result of the EU strategic response many European countries have adjusted their own industrial policies and strategies to implement I4.0 and raise the share of manufacturing in their economies. In Western Europe the major initiatives include "*Platform Industrie 4.0*" (Germany), "*Alliance pour L'Industrie du Future*" (France), "*Industria 4.0*" (Italy), "*Produktion 2030*" (Sweden), "*Industria Conectada 4.0*"

[14] The EC (2014:2) justified this response with reference to the facts that 3.7 million jobs have been lost in EU manufacturing between 2008 and 2013 and that the share of manufacturing in its GDP fell from 15.4 percent to 15.1 percent over the same period (See Eurofound, 2016).

(Spain) and "*Catapult High Value Manufacturing*" (UK) (see European Commission, 2017).

In an overview of these, the European Commission (2017) identifies similarities and differences in approaches and possible shortcomings. In terms of similarities, the Commission finds that the majority of I4.0 policies "aim at strengthening the respective country's industrial competitiveness and modernization and better ensuring the sustainable growth of the manufacturing sector" (p. 3).

In terms of policy approaches, the Commission notes differences in terms of whether countries focus predominantly on new product development or process improvements. Generally, most countries have made their I4.0 policies part of a broader development and industrial strategy, including often relating to socio-economic and environmental strategies. Within I4.0 they have then implemented measures to assist in the deployment of new technology (especially the Internet of Things and Cyber-Physical Systems) through for instance R&D incentives, loans, project funding, infrastructure provision and support for SME innovation.

As for shortcomings, the Commission notes that "national industry 4.0 initiatives tend to focus on technology and infrastructure, with skills development a secondary goal" (p.6). The Commission also notes that initiatives tend to be top-down in decision-making and implementation, and that there is a lack of cooperation amongst members states on this topic.

The CEEC8s have in recent years (mainly from around 2015-2016) followed suit with their own I4.0 initiatives. These are summarized in *Table 5*. From analyzing these initiatives, a number of comments are in order, which we will frame with respect to our approach (see Diagram 1) of three dimensions of technology, entrepreneurship and governance.

First, in almost all countries, initiatives follow the German "platform" approach, wherein the I4.0 initiative aims to create a dialogue and cooperation between various stakeholders, such as government, industry and the science and education sectors. In this respect, and also in efforts to improve the e-Government, existing policies also pay attention to the governance dimension of I4.0 readiness (see Diagram 1).

Second, in all of the region's I4.0 initiatives the focus is on digitization, technology diffusion into industry, and digital skills development. This reflects care towards the technological capabilities dimension of our I4.0 readiness index. As in the case of other EU countries' initiatives (see European Commission, 2017) the CEEC8 focus herein on expanding internet infrastructure and the penetration of the Internet of Things for industrial use. In Romania in fact this is the essence of the country's current strategic approach to deal with I4.0, with relatively little emphasis on the hardware and industrial aspects of I4.0 (see *Table 5*).

Table 5: National Industry 4.0 Industrial Strategies in CEEC8

Country	**Strategy**	**Key elements**
Bulgaria	Kontseptsia Industria 4.0[15]	Ambition the "Digital Transformation of Bulgarian Industry, 2017-2030". Focus: Innovation and technology diffusion. Strengthen relationships between science and industry. Skills and capacity building.
Czech Republic	Průmysl 4.0	A platform for industry-government interaction. Focus: Data and communication infrastructure, education and skills, flexible labour markets, global supply chains.
Hungary	IPAR 4.0 National Technology Platform/ Irinyi Plan	A platform for industry-government interaction. Ambition to be one of the most industrial economies in Europe and raise share of industry in GDP to 30 percent by 2020. Focus: Digital technology, digital transformation of industry, skills, export growth.
Lithuania	Pramonė 4.0[16]	A platform for industry-government interaction. Focus: Technology, infrastructure and digital skills.
Poland	Future Industry Platform	A platform for industry-government interaction. Raising awareness and demonstrate I4.0 technologies. Focus: Technology, digital transformation and business development, including SMEs.
Romania	National Strategy for Romanian Digital Agenda 2020[17]	Focus: ICT infrastructure, digital skills, internet penetration, e-Government services.
Slovakia	Smart Industry Platform	A platform for industry-government interaction. Focus: Technology adoption, R&D, education and skills, awareness of smart manufacturing.
Slovenia	Slovenian Digital Coalition / Slovenian Industrial Policy 2013	A platform for industry-government interaction. Focus: Digital skills, digitization of industry and digital regulation.

(Source: Authors' compilation based on European Commission (2017) and EC Digital Transformation Monitor Online[18])

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[15] See: https://www.mi.government.bg/files/useruploads/files/ip/kontseptsia_industria_4.0.pdf
[16] See http://www.industrie40.lt/platform/
[17] See: http://gov.ro/en/government/cabinet-meeting/national-strategy-on-the-digital-agenda-for-romania-2020
[18] See : https://ec.europa.eu/growth/tools-databases/dem/monitor/category/national-initiatives

Third, (with the exception of Poland) the initiatives tend to neglect the entrepreneurial capacity dimension. This is also a feature of the I4.0 initiatives in other EU countries. It is not the case that these countries do not have initiatives to promote entrepreneurship, or improve the business environment[19], rather these are not integrated or coordinated with their I4.0 strategies, and moreover, tend to neglect vital aspects for technology entrepreneurship, such as venture capital provision and the promotion of entrepreneurship to commercialize inventions and to find new opportunities for exporting and new export markets. The Czech Republic, which is top ranked in terms of both technological capabilities and governance, falls to second place when it comes to entrepreneurial capabilities.

Relatedly, R&D in the region is comparatively low and innovation activities in the CEECs differ significantly from that in the West. Around 55 percent of innovation expenditures in 2010-2012 in the CEECs were on the acquisition of machinery, equipment and software and only 39 percent on R&D. In comparison, Western EU countries spend 19 percent of innovation expenditure on the acquisition of machinery, equipment and software, and 73 percent on R&D (Radosevic, 2017). In the context of I4.0 it may be argued that R&D focusing on adapting and generating technologies for local specifications, as well as the commercialization of these efforts (through support for entrepreneurial start-up ecosystems) will need more attention. This needs to be stressed in the environment of I4.0 where countries may expect less FDI from the West, and less manufacturing exports to the West, as these countries reshore their production.

In the past, it was FDI and trade that brought in technology (Stojcić and Aralica, 2017) – in future the local entrepreneurship and innovation systems, focused moreover on export diversification, will need to play a greater role. As with regard to incentives and the promotion of the diversification of manufacturing exports towards non-traditional (non-EU) markets and to keep manufacturing exports to EU markets more competitive, the CEEC8 need to consider exchange rate policy as a tool to promote I4.0. *None of the current I4.0 strategies in the region considers this*. This may be a significant lacuna, given that maintenance of a competitive exchange rate (i.e. under-valued) is an important industrial policy tool – it has played a critical role in the industrial development of China and the East Asian Tiger economies.

Fig. 12 shows that since 1994 the CEEC8 exchange rates all appreciated – in effect reducing the international competitiveness of their manufactured exports.

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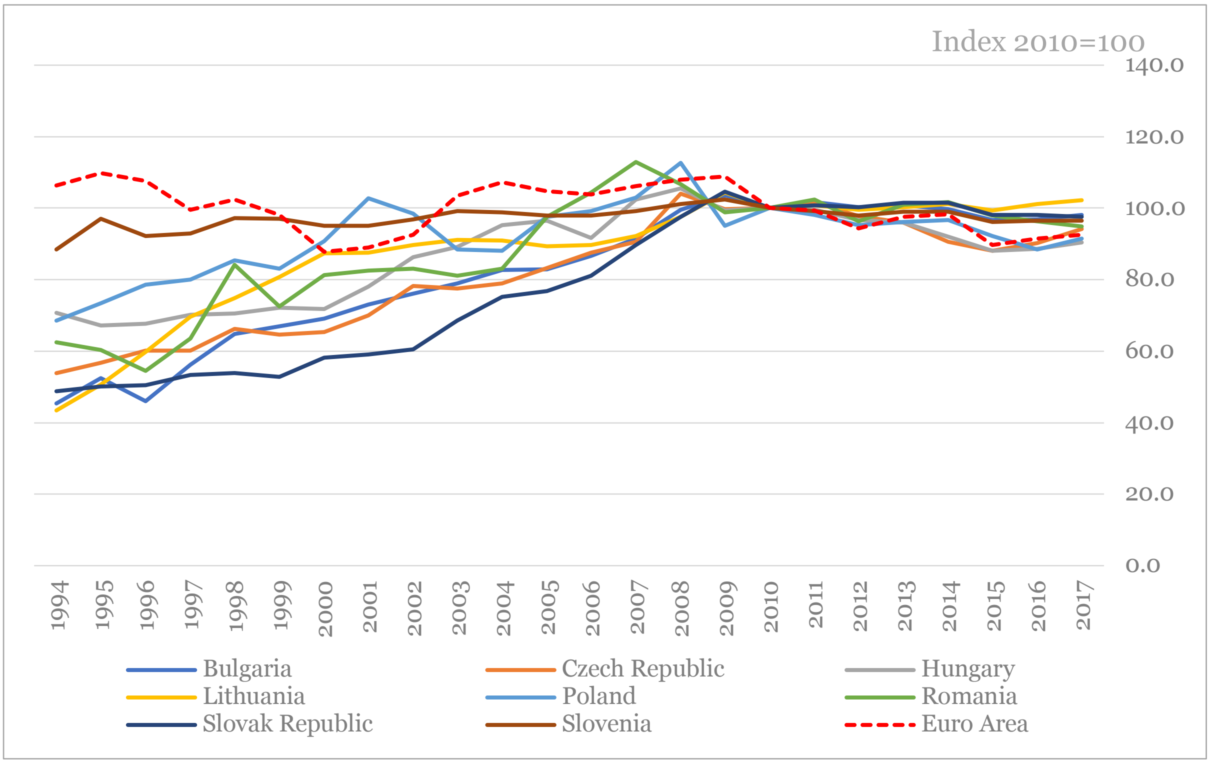
[19] Indeed, reform of the business environment, for instance to make it easier to do business, has been a common theme in the countries' policies at the end of the socialist era (Stojcić and Aralica, 2017).

Fig. 12: Real Broad Effective Exchange Rate for the CEEC8, 1994-2017



(Source: Authors' compilation based on Bank for International Settlements, retrieved from FRED, Federal Reserve Bank of St. Louis)

Moreover, *Fig. 12* shows that in recent years, especially after the global financial crisis, a number of CEECs have seen their exchange rates markedly appreciate against the Euro. Except for the Czech Republic, Hungary and Poland, all the other CEECs had by end 2017 currencies stronger than that of their major trading partner, the Euro zone. A further focus (combined with relative exchange rates) should also be on the identification[20] of alternative new markets and products for CEEC8 manufactured exports. A concerted effort to identify and develop opportunities in non-traditional markets (in addition to that of Western Europe) is strategically important.

Finally, the current I4.0 initiatives in the region are, like those in other EU countries, largely funded by government, in programs that hope to become self-sustainable in future by private sector funding; and furthermore, are characterized by little coordination and cooperation between countries. Here, our recommendation is that the CEEC8 countries seek more structural and long-term funding for their I4.0 initiatives, including for instance through supporting EU-level initiatives[21] to tax the digital platform-based giants (such as *Amazon, Google, Facebook*, etc.) based on how much income they generate in a particular EU country (the proposed "equalization tax"). In this, and more generally in addressing challenges to the implementation of

[20] E.g. one of the approaches to identify and investigate potential "unusual" suspects as the of the TRADE-DSM methodology. See e.g. Cuyvers et. al. (2012) and Cuyvers et. al. (2017).

[21] See e.g. https://euobserver.com/economic/138954

I4.0 posed by labour market and skills shortages, greater cooperation between CEEC8 is recommended, for instance through a regional "CEEC I.40 Platform".

5. Summary and Concluding Remarks

What is the future of manufacturing in Central and Eastern Europe in light of industry 4.0 (I4.0)? In particular, given that the bulk of manufacturing exports from Central and Eastern Europe and the bulk of foreign investment in its manufacturing are from Western Europe, where I4.0 is rapidly changing manufacturing, and given growing labour shortages in CEECs, the question is: will these countries face de-industrialisation in future?

To answer this question, we started this paper by analyzing the recent past of manufacturing development in the region, focusing on the I4.0 readiness of eight countries: Bulgaria, the Czech Republic, Lithuania, Hungary, Poland, Romania, the Slovak Republic and Slovenia.

First, we outlined the nature of manufacturing in the region and identify and described three distinct time periods of industrialization since 1990. This told a remarkable success story: the CEEC8 managed to make a transition from a socialist past to modern economies that started to reindustrialize after 1996 and subsequently made substantial progress in catching up to Western Europe in terms of GDP per capita, labour productivity and living standards. FDI from and exporting to Western Europe was a significant contributor.

Second, we explained the nature of I4.0 so as to identify measures for the readiness of the countries. We emphasized the premium that I4.0 technologies and business models places on agility, flexibility and customer orientation and the implication that this has for the location decision of manufacturing firms and plants.

Third, using measures reflecting three key dimensions of I4.0 readiness, namely *technological, entrepreneurial* and *governance* competencies, we conclude that the Czech Republic, Lithuania, Hungary and Slovenia are most I4.0 ready, and that Poland, Slovakia, Bulgaria, and Romania are the least ready in relative CEEC8 terms. For the latter this is a of concern, especially given that Poland and Romania have amongst the most substantial manufacturing sectors in the region: hence stand much to lose if they are not ready for I4.0.

Finally, we made a number of recommendations for these countries' industrial policies. Although each country should craft its own strategic response in terms of where it stands with respect I4.0 readiness, we called for all the countries in the region to do more to promote entrepreneurial skills and to diversify and grow both manufacturing products and export markets.

In this regard, we commented on a number of perceived gaps in the countries' I4.0 strategies and policies.

One is that the initiatives tend to neglect the entrepreneurial capacity dimension, in particular vital aspects for technology entrepreneurship, such as venture capital provision and the promotion of entrepreneurship to commercialize inventions and to find new opportunities both in the production of products for exporting and new export markets. In the past, it was FDI and trade that brought in technology but *in future the local entrepreneurship and innovation systems, focused moreover on export diversification, will need to play a greater role.*

A related gap identified is in the linking of industrial policy for I4.0 with trade and exchange rate policies. To promote the diversification of manufacturing exports towards non-traditional (and non-EU) markets and to keep manufacturing exports to EU markets more competitive, the CEEC8 need to consider exchange rate policy and focused export promotion (and trade facilitation) as tools to promote I4.0. It would seem that none of the current I4.0 strategies in the region explicitly considers these potential approaches.

This may be a significant lacuna, given that maintenance of a competitive exchange rate (i.e. under-valued) and trade facilitation are important industrial policy tools – they have played critical roles in the industrial development of China. In all CEEC8 members developments exchange rate appreciation occurred after 1994 with the result that today the majority of CEEC8 countries have to face I4.0 with the potential hurdle of an exchange rate that is un-competitive vis-à-vis that of its largest trading partner and competitor, the EU-Zone.

Finally, we concluded this paper by recommending that the CEEC8 countries should seek more structural and long-term funding for their I4.0 initiatives, including for instance through supporting EU-level initiatives to tax international digital platform-based giants (such as *Amazon*, *Google*, *Facebook*, etc.) based how much income they generate in a particular EU country (the proposed "equalization tax"). In this, and more generally in addressing challenges to the implementation of I4.0 posed by labour market and skills shortages, greater cooperation between CEEC8 is recommended, such as through a regional "CEEC I.40 Platform".

Appendix

Table A1: Population, GDP, Per Capita Income and Growth in the CEEC8

Country	Population, 2017	real GDP (US$) in 2017	Real GDP per capita, 2017 (US$)	Average GDP growth, 1995-2017
Bulgaria	7.075.991	58.815.148.233	8.312	3,70%
Czech Republic	10.591.323	241.262.838.218	22.779	3,20%
Hungary	9.781.127	153.053.569.271	15.648	2,85%
Lithuania	2.827.721	47.486.625.804	16.793	6,34%
Poland	37.975.841	598.166.351.607	15.751	5,96%
Romania	19.586.539,0	214.126.451.996	10.932	3,99%
Slovak Republic	5.439.892	108.238.366.186	19.897	5,74%
Slovenia	2.066.748	53.037.744.699	25.662	3,35%

(Source: Authors' compilation based on World Bank Development Indicators Online)

Acknowledgements

We are grateful for the useful comments and suggestions from participants in the Seminar on Industry 4.0 in Central and Eastern Europe, held on 23 November 2018 at the Delegation of Poland to the OECD, Paris, France. The usual disclaimer applies.

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