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Drivers of intangible assets accumulation as a prerequisite for Industry 4.0

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Abstract: Industrial revolutions are causing unprecedented changes in the country's economy. These changes are driven by new technologies and innovations. This is primarily based on the growing importance of intangible assets. These are the main characteristics of the ongoing industrial revolution. In the absence of a precise definition and indicators quantifying Industry 4.0, intangible assets are presumed to be the common basis of determinants of Industry 4.0. This paper presents the theoretical basis for determining the Industrial Revolution. Comprehensively describes the determinants of the accumulation of intangible assets. Implementing a panel regression technique with random effects shows the results. We identify the factors unlocking the accumulation of intangible assets. This is primarily in the area of government direct and indirect support for investment in R&D and other innovation assets. Also, it is about creating the environment to encourage private investment in innovation assets, intangible ICT assets and economic competencies.

1 Introduction and theoretical background

1.1 Industrial revolution in history

The first revolution with the industrial label is dated to the period 1760 to 1820. At that time, there was a shift from manual production to machine production, through the use of water and steam power. The second revolution, also known as the technological revolution (1870-1914). It is characterized by productivity growth and as a period of great economic growth. A major milestone was the invention of electricity, which provided the electrification of factories and the operation of the modern production line. Other benefits of the revolution were development of the international specialization of labour, the extensive development of the railway network and the development of the telegraph. This allowed for a faster flow of information, goods and peoples. However, a negative phenomenon of such rapid changes was the increase in unemployment, which was the result of the gradual replacement of labour activities by machines, which had previously been carried out by man [1].

The third is the digital revolution, otherwise known as the data revolution, which is being implemented to a greater extent and in a different form today. Significant advances in information and communication technology (ICT) and computing are occurring [2]. There is a massive use of computer and communication technologies in manufacturing processes. Thus, machines have started replacing the need for human power. At the same time, there is a decline in industrialization compared to previous revolutions and the emergence of services.

The fourth industrial revolution is referred to as "Industry 4.0". It was introduced in 2012, but only came to the attention of the general public in 2016 through the World Economic Forum in Davos. Industry 4.0 was initially defined as the German Federal Republic's strategy for the computerisation of production under the acronym "Industrie 4.0". The introduction of this initiative was mainly due to the decline in industrial production and productivity, paradoxically in the most industrially developed countries. The latter expect it to increase global competitiveness, especially in relation to the so-called emerging economies. The main objective of this concept was to help rebuild and increase the performance of the European Union's industry, i.e. 'reindustrialisation', building on the EU's industrial tradition and its new innovative potential [3]. The validity of this initiative for EU industrial policy is also confirmed by the European Commission in its 2012 strategy paper [4].

1.2 Industry 4.0

It is important to note that more than a hundred years passed between the first and second industrial revolutions and only thirty years between the third and the present revolution. We are already seeing rapid progress more or less online. The assumption is that this trend will peak within the next decade. The current setting of technology use in everyday life is a dramatic step in society's progress and is unprecedented in all of history. It is now essential to understand Industry 4.0 in a global context, as this transformation will be as fundamental to humanity in terms of scale, scope and complexity as no other technological change in history [5].

Professor Schwab [6] confirms that a range of new technologies will constitute an industrial revolution. The merging of the physical and the intangible, i.e. the digital world, will affect all disciplines of the economy and industry. The current industrial revolution is the only one among the three previous revolutions that represents a planned concept that is stimulated by the state. The main objective is the development of industrial production. Industry is a crucial sector within the economy, as its decline, development or modernisation affects the direction of the whole economy and other specific sectors of the economy such as trade, transport, and others [7].

Industry 4.0 also includes the integration of business partners and customers around the world. Its expected benefits are highly efficient manufactures that are coordinated in real time. This lead to the emergence of new services and business models. There is a consensus in the professional, not just academic, community on the defining manifestations and trends of the fourth-generation industrial revolution. These include new materials, the use of 'big data', the Internet of Things and the Internet of Services, artificial intelligence, sensors and microchips, cyber-physical solutions and new systems, new technologies and innovations, automation and autonomous production, robots, 'clouding', 3D printers, virtual and augmented reality, and so on [8].

The use of next generation technologies is currently at an early stage and we only know with certainty the theoretical potential they can achieve when fully exploited. According to [7] in terms of the so-called *Amara's Law*, we tend to overestimate the impact of new technology in the short term and underestimate it in the long term. Nevertheless, it is difficult to underestimate the future global impact of Industry 4.0, which will occur in most areas of business, socio-economic, tax, consumer behaviour, employment, education and other areas [9]. From our perspective, an important complex macroeconomic aspect that stakeholders need to prepare for is the question of how to ensure attractiveness and competitiveness for new investments.

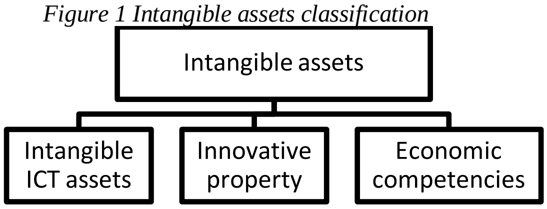
1.3 Accumulation of intangible assets

Recent decades have seen a gradual shift away from the view that a firm's competitive advantage is primarily based on size and strength, towards the view that it is based on intangible assets (intangibles). This shift and the existence of such a view is at the core of the evolutionary theory of the firm according to [10]. The firm is viewed as a "*social community*" whose productive knowledge defines comparative advantage. This theory is based on the principle of differential capabilities and the organizational structure of firms, which are defined by the level of knowledge. A fundamental characteristic of this knowledge is that it is not transferable between different enterprises. [11] presents that it is the distribution of knowledge in the economy that influences the heterogeneity of economic behaviour and governs the way in which competition is conducted. This distribution of knowledge is realized in the form of intangibles [12]. The important role of intangibles in companies was already realized at the beginning of the last century. Professor Veblén [13] argues that the essential basis of an industrial enterprise is its intangibles and the process of value creation in firms. This is largely created and supported by intangibles. The position of intangibles in capitalism is theoretically complemented by [14].

A comprehensive theoretical and methodological insight into intangible was laid down by the works of [6,15], which have established a stream of literature highlighting the role of intangibles and also provide an extensive analytical summary of this area of research. This has been followed by the development of multiple streams of literature addressing the impacts and effects of intangibles [16].

This form of capital, is an increasingly common form of corporate investment and a key contributor to growth in advanced economies. According to the [17], intangibles do not have a physical form and include the following assets shown in Figure 1.

Figure 1 Intangible assets classification



Source: own elaboration based on Corrado et al. 2010

Accurately quantifying the accumulation of intangibles is not at all straightforward, as is the case, for example, with tangible or financial assets, the price of which is determined by trading in the market. In the case of intangibles, the vast majority are accumulated by enterprises through internal research and development. The components of intangibles also include human capital and organisational knowledge, which are difficult to quantify as they are specific assets for a particular enterprise or type of enterprise. Therefore, the most common data source, the National Accounts, only report assets that have a certain market capitalisation, or assets that are derived from its costs. The industrial revolution and the development of ICT are causing the accumulation of assets to shift to intangibles. Currently, the rapid rate of accumulation of intangibles is rapidly moving away from the volume of accumulation of tangibles [18].

According to [15], the accumulation of intangibles is identified as one of the main determinants of innovation and growth. This assumption is already confirmed by the Endogenous Economic Growth Models, which emphasized knowledge and skills as the main determinants of economic growth. They also include the assumption of spillovers, which in the context of knowledge and skills generate sustained economic growth [19,20]. It is now evident that the accumulation of intangibles helps to build knowledge economies. The area of quantifying intangibles is relatively complex, as it is difficult to correctly determine what else can be considered as an investment in intangibles. The acquisition of any intangibles takes only two forms. Either it is acquired by acquisition, i.e. by purchase from other entities, or it is the result of the enterprise's own research activities.

1.4 Determinant of accumulation of intangibles

Thum-Thysen [13] defined four basic determinants that affect the accumulation of tangibles and intangibles. The *first determinant* is government and public sector support, which we disaggregate into direct and indirect support. Direct support includes grants and incentives that are directed towards the accumulation of intangibles. Indirect support comprises determinants whose change may indirectly affect the ability of firms to invest. Here we include the tax burden. The positive impact of some policies that stimulate the accumulation of intangibles, primarily R&D, has already been demonstrated. Therefore, we expect that direct and indirect government support can stimulate investment in intangibles. The *second determinant* is the macroeconomic stability and financial conditions of enterprises. Macroeconomic instability is generally a barrier to all types of investment, including those in intangibles. As a proxy for macroeconomic stability, we use the long-term interest rate, which determines the ability of enterprises to finance their business in the long term. Financial soundness represents the ability of enterprises to invest. We use the debt to equity ratio as a proxy for financial health. We assume that macroeconomic stability and financial condition will have a positive impact on the accumulation of intangibles. The *third determinant* is quality of human capital. According to Thum-Thysen [13], most types of intangibles are human capital intensive. We use the share of tertiary-educated people in the total population and the share of employees working in R&D and technology as a proxy for the quality of human capital. We assume that an increase in the quality of human capital will have a positive impact on further accumulation of intangibles. The *fourth determinant* is the regulatory framework. There are now a number of empirical studies that look at the effects of regulation on trade, markets, business and labour. These include, for example [21,22]. We expect that the introduction of new regulations will have a negative impact on the accumulation of intangibles. We primarily observe labor regulation, via the EPL (Employment Protection Regulation) index.

2 Methodology and data

In this section, we present the chosen empirical strategy, i.e. econometric panel regression. We will present the data used and their adjustment. Based on the previous section, we define the following research questions:

1. *Which factors will have a positively influence on the intangibles accumulation?*
2. *Which factors will have a negative influence on the intangibles accumulation?*

2.1 Empirical strategy

Implementing Hausman's panel robustness test [23], we confirm the panel fixed effects regression. The use of this empirical strategy is consistent with the structure of the data and is consistent with the econometric procedure in the study e.g. Thum-Thysen [13]. Since we are working with longitudinal data, the chosen method is suitable for capturing long-term trends and relationships. This is also true given the data used, where longer time series and a small number of variables are used in the model.

We confirm that the overall panel is robust. The benchmark equation is based on the neoclassical and acceleration models of IMF [24] and the extended model of Thum-Thysen [13]. Intangibles accumulation I (1) is a function of capital stock $\Delta K^{*}_{c,t-j}$ (2), where we include a lagged effect as we account for potential slow capital adjustment and a possible endogeneity problem. We denote this lagged effect by one year as j.

$$I_{c,t} = \sum_{j=0}^{J} \omega_j \, \Delta K^{*}_{c,t-j} + \delta_j K_{c,t-1} \qquad (1)$$

The model is based on the assumption that changes in capital are proportionally related to changes in economic output:

$$K^{*}_{c,t-j} = \mathrm{c}\Delta Y_{c,t} \qquad (2)$$

Combining the equations and then dividing by $K_{c,t-1}$, using the fixed effect and the lagged effect by one year, the following equation (3) comes out with the mathematical prescription:

$$\frac{I_{c,t}}{K_{c,t-1}} = \gamma_c + \sum_{j=1}^{N} \beta_{1j} \frac{\Delta GVA_{c,t-j}}{K_{c,t-1}} + \varepsilon_{c,t} \qquad (3)$$

where, $\frac{\Delta GVA_{c,t-j}}{K_{c,t-1}}$ represents the accelerator, expressed as a ratio of gross value added (lagged by one year) to total capital accumulation. We then extend the model to include other potential factors that may affect intangibles accumulation following the model used in Thum-Thysen [13]. Our benchmark equation is shown in the following equation (4):

$$\begin{aligned} lnY^{TOTINTG}_{c,t} &= \alpha_1 Accelerator_{c,t} \\ &+ \sum_{q\in Q} \beta_1 \ln K^{\mathrm{State}}_{c,t-1} \\ &+ \sum_{q\in Q} \beta_2 \ln K^{Macro\&Finance}_{c,t-1} + \sum_{q\in Q} \beta_3 \ln K^{Human\ Capital}_{c,t-1} \\ &+ \sum_{q\in Q} \beta_4 \ln K^{Regulation}_{c,t-1} \\ &+\alpha_2 lnSERV_{c,t-1} + \alpha_3 lnGHR_{c,t-1} + \delta_{c,t} + \varepsilon_{c,t} \end{aligned} \qquad (4)$$

where, c = country, t = time. $lnY^{TOTINTG}_{c,t}$ represents the dependent variable as the share of intangibles in total capital stock. We complement this model with an indicator of servicification and participation in global value chains (GVCs). Knowledge-intensive economies have become progressively more service-oriented. Industrial production is largerly carried out within GVCs. Global value chains are becoming more serviced and the industrial sector is incorporating more and more services, which could indirectly increase the role of intangibles in the industrial sector. We implement this extension of the model to include a variable that indicates the degree of servisification of the economy. In next section more details on the variables used are presented.

2.2 *Data used*

We use the 4 categories of determinants defined by Thum-Thysen [13] as explanatory variables. These data along with the sources are shown in Table 1.

Table 1 Variables used description

Variable	*Definition*	*Source*
Accelerator	Share of gross value added and total capital accumulation.	EU-KLEMS/ EUROSTAT
State support and public and private sector		
CIT	Indirect support - Statutory corporation	OECD
GERD	Direct-Total R&D expenditure (including private) / GDP	EUROSTAT
GOV_RD	Direct - Government R&D expenditure (excluding private) /	EUROSTAT
Macroeconomic stability and financial condition		
Interest	Long-term interest rate	Ameco
D/E ratio	Debt-to-equity ratio	OECD
Human capital		
PhD	Share of tertiary-educated people in the total population 25-64	EUROSTAT
Science	Share of people working in R&D and technology in total	EUROSTAT
Regulation		
EPL	Employment protection index/ collective redundancies	OECD
Global value chains		
SERV	Share of value added in TBS in total GDP	Svetová banka
GHR	Overall participation in global value chains	OECD-TIVA

Source: own elaborations

In Table 2, we present the descriptive statistics of the variables used. The total number of observations is 352.

Table 2 Descripitve statistics

	Mean	St. error	Median	ST. deviation
TOTINTG/ Capital stock	0.383	0.014	0.254	0.279
Accelerator	0.001	0.000	0.000	0.002
GHR	3.351	0.600	0.457	11.26
CIT	0.289	0.004	0.280	0.076
GERD	1.776	0.047	1.745	0.878
GOV_RD	0.604	0.011	0.595	0.202
Interest	4.839	0.141	4.500	2.637
D/E	5.130	0.221	3.852	4.137
PHD	22.84	0.449	22.60	8.418
Sciecne	23.01	0.347	22.50	6.514
EPL	2.617	0.037	2.579	0.693
SERV	0.615	0.003	0.617	0.050

Source: own elaborations

In total, we use data from 16 EU countries. The time series is from 1995 to 2016. We used sectoral data that were fully complete up to 2016. The EU-Klems database updates the data regularly. In the econometric analysis, we identify the factors that affect the accumulation of intangible assets. The available data are sufficient to illustrate important trends, which are supported by several scientific studies. We draw data on intangibles accumulation from the INTAN-Invest [6,25] and EUKLEMS database [26]. For the standard error, we observe very low values relative to the mean, and the standard deviation is quite low, which tells us that the data are mostly close to the mean. We present the results of the regression analysis in the following section.

3 Results

We use the accelerator as the main variable, which is the ratio of gross value added to total capital accumulation. This is the indicator that links investment and output. Among the explanatory variables, we also include intangibles that are not included in the National Accounts of countries, such as Economic Competence. This makes the analysis more detailed and allow us to emphasize the first and second research question.

The first group of factors that affect the accumulation of intangibles are State support and public and private sector support. We observe a negative impact of the statutory corporate tax. Its increase has a negative effect on the accumulation of intangibles, as it reduces the available resources that have to be paid in taxes. We do not include R&D tax incentives here. These can complement direct subsidies (GOV_RD) in building innovation processes.

We further distinguish between total expenditure on science and research (GERD) and public expenditure (GOV_RD). We show that public R&D investments that can effectively strengthen the public science base stimulate the accumulation of intangibles in the economy. Total R&D expenditure (GERD), which includes private

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investment, has a higher coefficient (0.235) than the estimated coefficient of government expenditure (0.214). These findings are consistent with our assumptions.

The second group is macroeconomic stability and financial condition, where we include the long-term interest rate (Interest) and the debt-to-equity ratio (D/E ratio). As expected, we observe a negative estimated coefficient on these variables as rising interest rates have a negative effect on firms' investment activity. The same is true for the D/E ratio, as extremely indebted firms will not allocate investment to the acquisition of new intangibles.

The third group is the availability and quality of human capital, where we include the share of tertiary educated people and the number of skilled workers in R&D and technology. We assume a high complementarity between R&D investment and skill accumulation, as confirmed by Thum-Thysen [13]. We demonstrate the positive impact of high levels of tertiary education on increasing the accumulation of intangibles. The same is true for the R&D and technology employment variable.

The fourth group is the regulatory framework. Here we consider the regulatory behaviour of countries that may lead to difficulties in accumulating intangibles. It is true that the more regulations the less investment in intangibles, primarily R&D [21]. We use a regulatory index referred to as EPL, which focuses on legal protection of employees, collective bargaining and dismissals, and hiring on temporary contracts. Specifically, we use an index regulating collective dismissals. As expected, our results confirm the negative impact of the regulatory index. Excessive EPL may constrain the efficient reallocation of factors and may reduce productivity [27]. Our results are consistent with the findings of Thum-Thysen [13]. A rigid labor market can have negative effects on firms' efficiency and productivity.

The last group are variables that are related to participation and the form of organized production. There is a paradigm shift in the organisation of GVCs through the increasing involvement of services. It is the SERV variable, which expresses the share of the volume of value added generated in the service sector in GDP, that indicates to us how servisificated a country is. We show that participation in GVCs and a high share of servisification has a positive effect on the accumulation of intangibles.

Table 3 Results of panel data regression analysis

	TOTINTG_ln								
Fixed Effect	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Accelerator_ln	0.355***	0.331***	0.348**	0.452***	0.370***	0.411**	0.388***	0.318**	0.316***
	(0.034)	(0.033)	(0.034)	(0.039)	(0.045)	(0.028)	(0.033)	(0.035)	(0.029)
CIT_ln $_{t-1}$	-								
	(0.038)								
GERD_ln $_{t-1}$		0.235***							
		(0.037)							
GOV_RD_ln $_{t-1}$			0.214**						
			(0.044)						
				-0.075***					
INTEREST_ln $_{t-1}$				(0.015)					
D/E_ln $_{t-1}$					-0.070***				
					(0.019)				
PHD_ln $_{t-1}$						0.474**			
						(0.035)			
SCIENCE_ln $_{t-1}$							0.469***		
							(0.068)		
EPL_ln $_{t-1}$								-	
								(0.093)	
SERV_ln $_{t-1}$									2.108***
									(0.174)
GHR_ln $_{t-1}$	0.800***	0.716***	0.846**	0.895***	1.008***	0.257**	0.572***	0.872**	0.559***
	(0.073)	(0.071)	(0.065)	(0.061)	(0.059)	(0.073)	(0.083)	(0.062)	(0.061)
Balanced	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of Obs.	336	336	336	336	336	336	336	336	336
R2	0.521	0.550	0.526	0.526	0.491	0.675	0.557	0.530	0.652
F_stat.	***	***	***	***	***	***	***	***	***
Hausman	0.000	0.000	0.000	0.000	0.000	0.000	0.0067	0.000	0.000

Source: own elaborations; * *, **, *** indicates statistical significance at the level 10%, 5% and 1% levels.

4 Conclusions

Throughout history, industrial revolutions have caused dizzying changes in economies, businesses and people's lives. The Industrial Revolution, known as Industry 4.0, is having the greatest impact [28,29]. The accumulation of intangible assets has great potential to influence the way Industry 4.0 is implemented.

We have confirmed in a sample of 16 EU countries that public direct and indirect support, together with available and quality human capital, has the potential to positively stimulate the accumulation of intangibles. Conversely, barriers that negatively affect the growth of intangibles include macroeconomic and financial corporate instability and the regulatory framework.

We indetify the factors unlocking the accumulation of intangibles. This is primarily in the area of government direct and indirect support for investment in innovation assets - R&D and other innovation assets. It is about creating the space to encourage private investment in innovation assets, intangible ICT assets and economic competences. It is associated with the macroeconomic stability of the country, which creates all the preconditions for direct and indirect state support.

A significant driver positively influencing the accumulation of intangibles is the development of human capital quality. We have demonstrated that highly skilled human capital has a substantial impact on the accumulation of intangibles. This relationship may hold *vice versa*, where investments in intangibles have the potential to stimulate workforce development.

An important element is also the servicification of GVC, which means that the service sector also contributes to industrial production, encompassing activities characterized by a high degree of value-added. This is a significant factor in developed economies that stimulates the accumulation of intangibles, even in industrial production.

A proper understanding of the factors that influence the accumulation of intangibles can help policy makers to adopt legislative frameworks. Set the regulatory framework, create conditions for stable corporate financial health, improve the business environment and ensure a sustainable macroeconomic balance. Implementing the right policies can thus stimulate investment in intangibles, creating a knowledge-based economy that can result in improved adaptation of Industry 4.0.

The limitation of the research is to identify in more detail the factors influencing the accumulation of intangible assets. Future research could be directed towards a separate investigation of the impact of factors on specific types of intangible assets, such as ICT intangible assets, innovation assets and economic competencies.

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