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Industry 4.0 Wireless Networks and Cyber-Physical Smart Manufacturing Systems as Accelerators of Value-Added Growth in Slovak Exports

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Abstract: Industry 4.0 integrates smart and connected production systems that are pivotal in predicting and supporting production in real-time, leading to sustainable organizational performance. In manufacturing, it may increase productivity, sustainability, and energy efficiency, while optimizing competitiveness. The main purpose of this paper is to determine the impact of Industry 4.0 on the Slovak economy through a secondary data analysis in the automotive industry, which is the leading sector in the country. The paper aims to provide a comprehensive analysis of the various opportunities that are available in the value-added growth of car exports in Slovakia. It also explores the case study of PSA Group Slovakia, which highlights the importance of the Industry 4.0 concept in boosting the country's export growth. The paper proposes a series of recommendations and steps to improve Slovakia's innovation environment.

Keywords: Industry 4.0; globalization; value-added; global value chain; digitization; innovation; export; automotive industry

MSC: 37M99

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1. Introduction

Globalization, as a determining factor in the expansion of national economies, is the result of the culmination of a whole system of previous development processes, such as deepening internationalization and integration, expanding at the interdepartmental and transnational levels, and engaging in large-scale specialization and cooperation [1]. Recent scientific and technical knowledge has pushed this trend to such a degree that a new organization of economic life is necessary for its effective use. The theme of globalization includes a complex of themes and issues. Global industry and value chains are integral parts of international trade, offering developing countries the opportunity to better integrate, reduce poverty, and create new jobs, while furthering production and innovation across cyber-physical production networks. On the one hand, globalization as such offers positive effects in terms of sustainable economic growth, development, better working conditions, and environmental cooperation; but on the other hand, its extremely complex nature, lack of transparency, and weakening of commitments can lead to increased violence, escalated risk of human rights violations and of environmental regulations, and growing tax fraud [1].

There are currently several trends affecting the global industry, whether it is the COVID-19 pandemic [2], the protectionism of several countries, the growing stability of developing states, the growth and decline of commercial services, or the overall dynamics of the world economy [3]. In any case, the positive effects outweigh the negative ones, and ultimately, the existence of international trade, global value chains, and the implementation of the latest trends, such as Industry 4.0, is inextricable [4].

The main aim of the paper is to analyze the development of the Industry 4.0 concept—a current trend of digitalization and related automation of production—as a key to the growth of sustainable business performance in specific Slovak national conditions, in particular, in the automotive industry sector. Since 2007, Slovakia has been the world's largest producer of cars per capita. The automotive industry is the crucial industrial sector of Slovakia, which is the reason why the results of this study are important at both sectoral and national levels. Focusing on the importance of the automotive industry and the growth of added-value, the paper briefly demonstrates the impact of Industry 4.0 on the international trade structure and changes in the global value chains, which is the main contribution of the study.

Our specific contributions clarify how algorithm-driven sensing devices, big geospatial data analytics, and intelligent transportation applications are harnessed in the Slovak automotive industry for configuring smart sustainable urban mobility behaviors in terms of vehicle routing and navigation, traffic planning and analytics, and deep learning-based sensing technologies. We show how smart sustainable intelligent transportation systems and intelligent vehicular networks integrate deep learning-based sensing technologies, big geospatial data analytics, and driving perception algorithms. Slovak automotive companies as networked transport systems develop on connected vehicle technologies, intelligent transportation planning and engineering, and computer vision algorithms.

The study is divided as follows: the next part of the paper presents our research into the literature on which the whole study is based, from global megatrends to a separate revolution of Industry 4.0. The Material and Methods part of the study analyzes the available data and methods through which it is possible to decide on the applicability of this phenomenon to the Slovak industry. The following part interprets the obtained results and then presents a discussion of the various implications of Industry 4.0 in connection with increasing added-value for Slovakia. The last part of the study is the conclusion, where all the data obtained so far are summarized, configuring potential visions for the future.

2. Literature Review

The study focuses on the topic of the Industry 4.0 developed on deep learning-assisted smart process planning, but in connection with this issue, in theoretical terms, it is necessary to recall and characterize the world economy in the era of globalization, followed by transnationality and foreign direct investment, global value chains, and exports. These subtopics are closely related to the main one and part of its evolution, so the first part of the research is devoted to them.

The very first concept of the global value chain was introduced by Gereffi (1994) based on the specific example of the clothing industry [5]. Porter (1985) laid the foundation stone of such knowledge when he explained to a certain extent that the buyer is willing to pay for what the company provides him, and began using the term "global value chain (GVC)". He continued his analysis to the present, his main area being the competitive position of companies and their struggles. GVC represents a course of activities in society, in which the value of its products and services arises [6–8]. Mugge [9] claims that the added value may primarily be analyzed in the countries that create this value through participation, with such economies also benefitting the most from it. In a link to globalization and its pressures, Mugge [9] explains a major shift in removing isolated barriers to foreign trade. According to Ye et al. [10], the goal and end effect of global value chains is to achieve an optimal input-output ratio. The importance of international trade and its permanent dynamics are due to the onset of various factors, which in terms of their weight and impact on this trade are often referred to as megatrends [11]. One of them is transnationality, which has brought new forms to international economic relations, intra-company international trade, agreements on inter-corporate cooperation, and others [1]. The key players are transnational corporations, which are exclusively linked to foreign direct investment (FDI). They represent all transactions carried out between the direct investor and the company.

FDI exports affect transnationality in two ways, either replacing it or supporting it [12]. FDI reflects a long-term interest in controlling a resident enterprise in another country by resident entities in an economy [11]. Gray and Kovacova [13] draw attention to the essence of scientific progress and see it as the most important and significant catalyst for the dynamic growth of international trade. Thanks to the development of data-driven technologies and cyber-physical process-monitoring systems, the value chain is being virtualized, thus reducing barriers to entry for an increasing number of marginal service providers through outsourcing or offshoring [14]. According to Minarik et al. [4], the history of globalization shows that two dimensions of its development are of major importance: in particular, significant changes in the technological world of production, as well as the diversity of social and economic forms. The first part of the research is related to [15,16] that describes the four industrial revolutions and their significant impact on globalization.

The next part of the research is on the topic of industry and its fourth revolution. The concept of Industry 4.0 was first described by Kagermann and Wahlster (2011) at an exhibition in Hannover, Germany. It was constructed as a strategic program for the development of advanced manufacturing systems, to increase the productivity and efficiency of the national industry [17]. After the passage of the third revolution, according to Zabojnik [18], Industry 4.0 was launched using the Internet in all areas of industrial production, enabling real-time machine-machine, man-machine, and man-man communication [19]. The Internet is currently the world's most comprehensive network, which is why Clayton and Kral [20] mention self-configurable networks capable of autonomous configuration as a phenomenon of the 21st century. Clayton and Kral [20] also predict Industry 4.0-based mass expansion of the Internet into all areas of human activity and the interconnection of real worlds with virtual ones, with the interconnection period lasting 10–30 years. Yang and Gu [21] define Industry 4.0 as the incorporation of Internet technologies into factory production networks, the use of which will bring significant output gains, real-time interconnection of shop floors, and a link between production and manufactured items' sales. In the field of intelligent racing, Hermann et al. [22] refer to the possibility of achieving the desired state of networking based on real-time data, both from the physical world and from the virtual, i.e., obtained online.

Digitization is strongly associated with Industry 4.0, a concept that Klingenberg et al. [23] use as an indication of horizontally integrated processes within the value stream. This flow includes the production and use phase (Industry 4.0 and Internet of Things), where the term "digitization" unites these two concepts. By applying Industry 4.0 to international trade, according to Rogers and Zvarikova [24], annual efficiency gains in the range of 6–8% will be achieved. Ruttimann and Stickli [25] point out the growing need to implement the networking of data-driven technologies and achieve full connectivity. The smart industry in Slovakia attempts to integrate cyber-physical production systems across the entire economy and its conditions [26]. The difficult-to-define issue of Industry 4.0 is presented by Kovacova and Lewis [27], who understand it as the transformation of production from separate automated units to a fully automated and continuously optimized production environment. This is achieved by creating completely new global networks based on the interconnection of production facilities into cyber-physical production systems constituting smart factories. Mehmann and Teuteberg [28] understand the digital value chain as a vision that will result in a higher product quality and shorter delivery times. According to Galbraith and Podhorska [29], Industry 4.0 is based on three pillars: traditional industry, digital technologies, and the Internet. The expression of Industry 4.0 will take place mainly in the areas of communication links and artificial intelligence. The potential benefits and risks that Industry 4.0 will bring are reported by Sony [30] on several points, highlighting that the positive effects outweigh the negative ones, and its onset is inextricable.

Dalenogare et al. [31] draw attention to changes not only in all areas of the economy but also in the social spheres of society. Digitalization will affect the interconnected supply chain, reducing costs and better managing the entire process from start to finish by use of industrial artificial intelligence. Industry 4.0 should be approached by looking at how data can create value and what role each piece of technology plays, that is, its originality/value [23]. This study is a direct link between Industry 4.0 technologies and a key source of this revolution, real-time big data analytics. Intelligent goods produced by intelligent manufacturing are described in some studies [31,32] explaining the development of the role of personnel in intelligent work. Digitization and robotic wireless sensor networks will significantly improve the value chain by increasing efficiency, reducing costs, and creating more collaboration and innovation through real-time advanced analytics [33]. Said et al. [34] define and understand Industry 4.0 through four basic features, i.e., vertical interconnection of intelligent production systems, logistics, production, and services in cyber-physical system-based smart factories. Subsequently, horizontal integration of global networks will result in networking of business partners and customers. Lawrence and Durana [35] talk about stabilizing the concept of Industry 4.0 between industry experts and academia, and they point to the need for cooperation, although most researchers propose that the rise of Industry 4.0 will not be a revolution but an evolution in terms of artificial intelligence-driven big data analytics. Clayton and Kral [20] explain Industry 4.0 as the advancement of automation technology, the flexibility of which will depend on the innovation intent and policy of companies, on education, and on a quality workforce and skills. According to Lawrence and Durana [35], Industry 4.0 is built on the fact that people, machines, equipment, logistics systems, and products can communicate and cooperate directly with each other. Zavadska and Zavadsky [16] also contribute to the topic of digitization, highlighting the importance of digital data and the prompt responses of the management in business strategy planning. Industry 4.0 brings dynamic change that cuts across real-time sensor networks.

Global development can bring cutting-edge advancement of national economies and thus move countries' level of innovation significantly forward [16]. The measurement of the potential of Slovakia for the integration of Industry 4.0 is given by the DESI Index, which is created by the European Commission [36]. Assimilation, transformation, and the use of knowledge from the manufacturing environment enable companies to engage in both exploratory and exploitative innovation strategies [37]. Industry 4.0, according to Lăzăroiu and Harrison [38], relies heavily on the Internet of Things (IoT) and smart sensors such as smart energy meters [39]. Zhong et al. [40] describe extensive possibilities for real-time data processing using mathematical optimization models based on multi-correlation dependencies. Given the ongoing threat of the COVID-19 pandemic, Belhadi et al. [41] suggest that cooperation between supply chain stakeholders will be necessary to overcome the challenges of the crisis and accelerate the use of digital technologies. Digitization entails investing in adequate measures to adapt to digital transformation so that companies will have higher profits while optimizing their productivity and competitiveness by utilizing product decision-making information systems. From the consumer's point of view, there will be access to more and better services, giving them greater satisfaction with the services they use to meet their requirements.

3. Materials and Methods

One of the challenges in implementing Industry 4.0 is standardization. In this regard, it seems almost necessary to subject all standards, including in-house ones, to the requirements and international criteria developed together with major global players across international platforms [36]. Above all, there is a need to find an answer to the question of whether Industry 4.0 will provide the EU with a leading position in competition in global markets, or whether its implementation is essential to maintain its current position by integrating sustainable manufacturing and the Internet of Things. Or, at worst, whether the international diffusion of technology throughout multinational corporations will result in industrial leadership inevitably shifting to fast-growing economies such as China [36].

To conduct the analysis, and achieve the main aim of the paper, secondary data analysis was used. Secondary data is the information that has already been collected through primary sources and made readily available for researchers to use in their own research. In our study, the main focus was on government publications, websites, books, journal articles, internal records, and finally, the findings of the analysis were supported by a questionnaire [42].

For a brief illustration of the strength of China, this section provides the crucial data on this phenomenon in Slovak conditions, which is necessary to illustrate the general situation in the country. Table 1 gives an overview of the world's largest exporters and their development in recent years. It is necessary to address the position of individual countries on this issue, as, under the influence of the latest megatrends such as COVID-19, protectionism, and the decline in commercial services (by 21%), some countries are maintaining their position, while some are dropping off significantly in terms of exported goods [43,44].

Table 1. Export performance of companies from the largest economies in 2019 (%). Source: Authors' compilation.

Order (GDP)			State	GDP (bl-US)	Export (bl-US)		Total Export	Export Per.
					Goods	Services		
2020	**2019**	**2014**	**World**	84,538	17,583	4914	22,497	26.6%
1	1	1	USA	22,675	1431	705	2136	9.4%
2	2	2	China	16,642	2590	280	2870	17.2%
3	3	3	Japan	5378	640	160	800	14.9%
4	4	4	Germany	4319	1377	311	1688	39.1%
5	6	10	GB	3124	399	342	741	23.7%
6	5	6	India	3049	275	203	478	15.7%
7	7	5	FR	2938	475	246	721	24.5%
8	8	9	Italy	2106	496	87	583	27.7%
9	10	7	Canada	1883	390	86	476	253%
10	12	11	South Korea	1807	513	87	600	33.2%
11	11	8	Russia	1711	337	47	384	22.4%
12	9	12	Brazil	1492	209	28	237	15.9%

As may be seen with the export performance (measured by the share of exports of goods and services versus the gross domestic product with the current prices), over three years, the US did not fall from the first position for GDP growth. However, the export performance only reaches 9.4%. On the other hand, China is second for GDP growth (16,642 billion) and one of the largest exporters, with a performance of almost 17.2%. A few decades ago, China was mainly an agrarian country. It could not be said, for a long time, that it was a massively technology-oriented country; instead, its citizens had a completely different mentality [35]. As a reason for the growth that can be seen in the table, China was the first to control the COVID-19 pandemic, meaning its exports and production of goods were not as significantly impacted as in other countries. Other reasons may be the work ethos, politics, room for innovation, and a sizeable workforce.

From the EU's point of view, Germany's exports, on which Slovakia is partly dependent, clearly dominate. Its export performance is almost 40%, which represents 1688 kinds of exported services and goods. The German market is also focused on more highly demanded products with high added value, especially cars (e.g., VW, BMW, and Mercedes Benz). The influence in these areas significantly encroaches on the issue of Industry 4.0, where Germany develops its vision, especially in the engineering and automotive industries. As hot news for the German market, the construction of a new car company, Tesla, is introducing a completely different method of production that will be capable of producing almost 700,000 units a year. It is a matter of casting the whole parts and taking a gentler policy on car battery production. This means extreme competition for Germany and its market (Tesla is already the best-selling electric car in the EU). When looking at exports in terms of the amount of value-added, countries such as Germany, Japan, and China export products and services with higher value-added than those from Slovakia. The value-added in the Slovak territory did not change greatly in the 10 observed years (2005–2015), if anything taking a declining trend. In the example of the automotive industry, in 2012, the value-added for products had fallen to 2.8 billion euros. The following Figure 1 can help provides a current comparison of European countries in terms of export value-added (the values were mapped in 2019, representing the last available information).

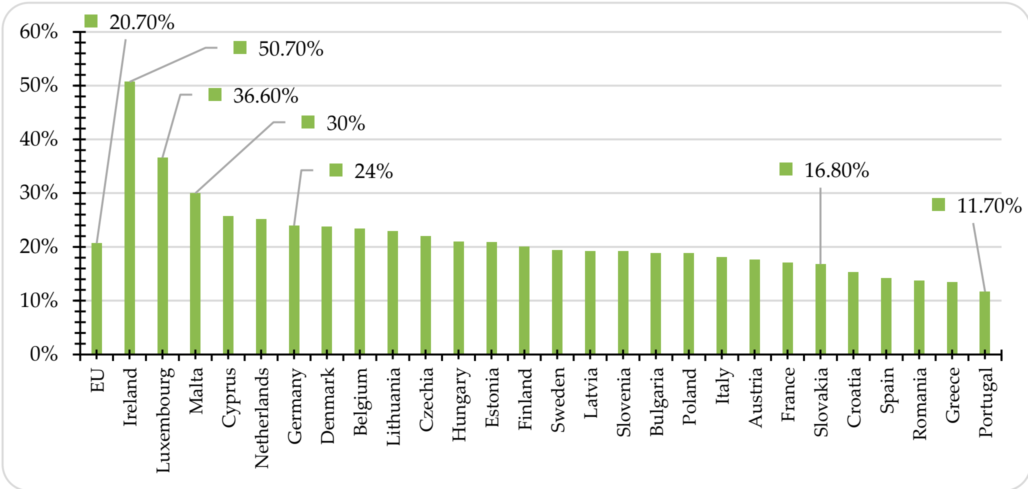

Figure 1. Share of value-added supported by exports. Source: Authors' compilation according to www.ec.europa.eu (accessed on 4 June 2022).

Looking at the exported value-added within the EU, it is important to recall and point to the great strength of Ireland (approximately 51%). Ireland's exports include mainly heavy machinery but also computer components and chemical products. Luxembourg is second and Malta is third. Germany produces 24% of value-added exports thanks to its strong engineering and automotive industries. Slovakia is in the 22nd position (16.8%). As already mentioned, Slovakia is an assembly-based country, where more is produced but less is added [36]. In front of Slovakia is France, which has not managed the COVID-19 pandemic as effectively as, for example, Germany or China. The last place is occupied by Portugal, a country of tourism, where added value dominates mainly in commercial services (tourism), which have fallen by about 21% worldwide as a result of the current public health crisis. As mentioned, the driving force of the Slovak economy is mainly the automotive industry, and this can be seen in the following Table 2.

In total, up to 30% of all investment projects are projected in the automotive industry, including component manufacturers, followed by the electrical and mechanical engineering industries. Taken together, almost half of the industry is exclusively linked to the automotive sector, deploying driving perception algorithms, big geospatial data analytics, and vehicle routing and navigation systems. The largest investors in Slovakia in the last 18 years have been Germany and South Korea, with about 29%, again mainly in the automotive and engineering industries (Germany—VW, South Korea—KIA) [45].

It is necessary to recall and characterize the significance of FDI. Foreign investors are interested in investing in Slovakia at this point, seeking to achieve smart factory performance. In the past, these investments were an essential part of the Slovak economy, which grew very slowly, and without the help of these investment projects, its growth could not have progressed so much. The automotive industry dominates the Slovak economy, but only at the level of assembly work. This is a problem that should be solved by massive support for research and development (e.g., through cognitive automation), dual educational programs, and most importantly, a completely differently oriented innovation policy. It should become a country that sets the trend; not one that just has to adapt to keep up with other countries. A much higher added value of the Slovak economy will be the key to its successful future.

Table 2. FDI stock by sector and territorial structure (2002–2020).

FDI STOCK IN SVK			
SECTOR	**%**	**TERRITORY**	**%**
Automotive industry, including subcontractors	30%	Germany	19%
Electrical industry, including subcontractors	13%	South Korea	10%
Engineering industry	11%	USA	7%
Chemical industry, plastics processing, and pharmacy	8%	Austria	7%
Metalworking industry and metal surface treatment	7%	Slovakia	6%
Business service centers	5%	Italy	5%
Information and communication technologies	5%	Denmark	5%
Wood and paper industry	4%	France	4%
Other services	3%	UK	4%
Textile, leather, and clothing industry	3%	Belgium	4%
Logistics and transport services	2%	Czechia	4%
Furniture and sanitary industry	2%	Switzerland	3%
Building industry	2%	Spain	3%
Research and development	2%	Netherlands/Japan	3%
Others	3%	China Others	1% 12%

Source: Authors' compilation.

After the secondary data analysis, which revealed the development of Industry 4.0 in Slovak conditions, the following methodological steps were followed to achieve the main aim of the paper:

1. A study of secondary sources (Sario, economy.gov.sk, datacube, Statistical Office of the Slovak Republic) to map the export performance of national economies and the development of the automotive industry in Slovakia;
2. A questionnaire, which was prepared with employees working on Industry 4.0 and digitalization of a company's production; the answers given were listed and characterized and key conclusions of this questionnaire identified. The first goal of the questionnaire was to find out the knowledge of the employees of the selected companies about the Industry 4.0 concept. The second goal was to determine the readiness of the selected companies for the transition to a digital company as a tool for introducing technological products and process innovations to the company, and thus, increased added value of the company [46]. The prerequisite was the establishment of innovative approaches based on the transformation (upgrading) of GVCs at the level of process upgrades and/or product developments for added value growth (about 20 people from four companies were contacted; this research took place in early January to April 2022);
3. Identification and a broader analysis of current trends in the automotive industry, and the implications of Industry 4.0 for the Slovak automotive industry.

4. Results and Discussion

The purpose of the study was to identify the current situation of Industry 4.0 in the automotive sector, express opportunities for value-added growth, and identify current trends and visions for the future in intelligent transportation planning and engineering, algorithm-driven sensing devices, and traffic planning and analytics. We then carried out a case study to map car companies' readiness to move toward the digitalization of production, i.e., to the implementation of the Industry 4.0 strategy, which will significantly increase the added value of their product portfolio in subsequent exports by leveraging industrial big data analytics.

4.1. Automotive Industry 4.0

The nature of commodities exported by the automotive industry in Slovakia is broadly focused on passenger cars (HS 8703) and vehicle parts (HS 8708). Volkswagen Slovakia had the largest share of the exports of Slovak cars in 2017, representing 99.5% of its revenues, followed by KIA Motors Slovakia (98.5%) and PSA Slovakia (94.3%)—see Figure 2 [36].

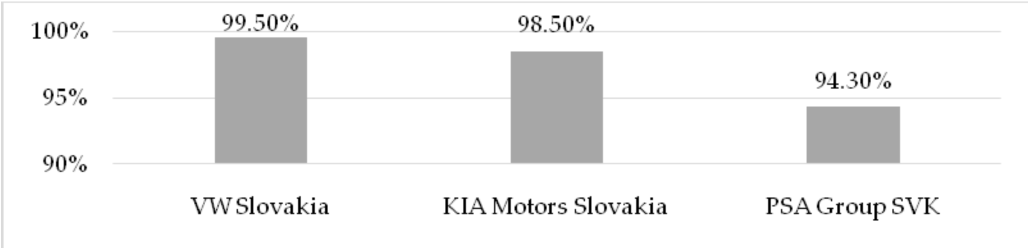

Figure 2. Shares of exports in sales of selected car manufacturers in 2017 (%). Source: Authors' compilation.

In terms of the territorial structure of Slovak passenger car exports (2017), Slovakia had the highest share of exports to Germany (15.20%; 2,227,301 euros), follow not far behind by France (13.47%). Other important import markets for Slovak passenger car exports are the UK (10.78%), the USA (9.59%), etc. (Table 3 [36]).

Table 3. The most important export markets for Slovakia in HS 8703.

	Import Country	**Import Value (th. eur) 2017**	**GDP p.c. (eur) 2017**
1	Germany	2,227,301	44,469.91
2	France	1,974,222	38,476.66
3	UK	1,579,664	39,720.44
4	USA	1,405,409	59,531.66
5	Italy	923,397	31,952.98
6	China	792,630	8826.99
7	Austria	701,367	47,290.91
8	Spain	689,193	28,156.82
9	Russia	484,441	10,743.10
10	Poland	340,627	13,863.18

Source: Authors' compilation.

In vehicle parts production, there is a mismatch between the contribution to production and the value-added. The HS 8703 branch accounts for 13.1% of the total value of gross production in Slovakia, but only 6.6% of the total value-added (for 2015). However, thanks to automation and high robotization, car production generates about two times the value-added per employee based on the average for the Slovak economy [45].

According to Figure 3, a declining nature of gross value-added per employee in Slovakia (40%) is evident; on the other hand, the Czech Republic's innovation policy drives growth (48%) and provides high value-added [36]. Compared to OECD and EU28 countries, Slovakia needs approximately two times more foreign added value (which it imports) for exports. Slovakia's gross exports are almost half (44.8%) imported foreign added value (dominated by industrial production).

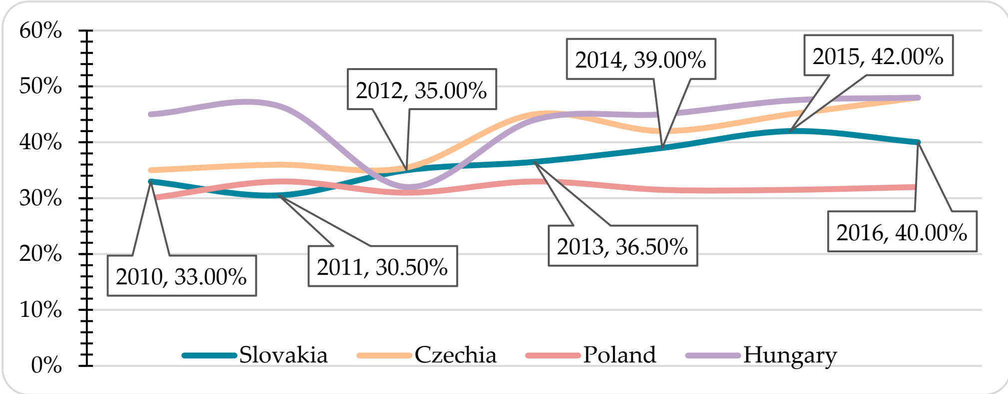

Figure 3. Gross value-added per employee under V4 2010–2017. Source: Authors' compilation.

The export of Slovakia in 2019 once again confirms the dependence on the automotive industry (33.4%—currently increased by 0.6%) and also explains the lower added value, see Table 4, as only completed cars were exported from Slovakia [41]. The second most dominant industries were electrical machinery and equipment (17.10%), followed by other machinery and equipment (12.30%), and iron, steel, and other metals (9.95%). Plastic and rubber were exported from Slovakia in 2019 at 5.45% of the exports.

Table 4. Exports from Slovakia in 2019.

Exports from Slovakia in 2019 (90.3 bl. eur)	
Vehicles and their parts	33.40%
Electrical machinery and equipment	17.10%
Machinery and equipment	12.30%
Iron, steel, and other metals	9.95%
Plastic and rubber	5.45%
Mineral fuels, oils, and products of their distillation	2.91%
Others	18.89%

Source: Authors' compilation.

Other exported raw materials were mineral fuels, oils, and products of their distillation (2.91%). In the automotive industry, the TiVA (trade in value-added) parameter (the share of foreign value-added in the gross exports—Table 5), in 2016, was highest for Japan (10.4%), Brazil (14.8%), and China (15.8%) [36,45].

Table 5. Development of the share of foreign value-added in gross exports—automotive.

Development of the Share of Foreign Value-Added in Gross Exports—AI					
	2012	**2013**	**2014**	**2015**	**2016**
SR	60.5	60.8	59.4	59.6	59.9
Hungary	64.4	64.2	64.5	54.4	60.4
Czechia	49.3	49.2	50.6	54.3	50.5
Poland	41.9	42.5	42.2	39.3	42.6
Germany	27.8	26.7	26.3	24.3	25.5
Austria	45.0	46.5	46.5	41.4	44.6
GB	35.7	32.3	30.1	29.2	31.0
EU13	51.9	52.1	52.7	51.4	52.0
EU28	34.5	33.6	33.3	31.5	32.7
USA	26.3	24.6	26.3	23.7	23.8
China	19.3	19.4	19.3	16.3	15.8
Japan	11.6	12.9	13.6	12.0	10.4
India	32.8	33.7	31.3	28.1	23.5
Russia	31.6	33.2	31.5	30.5	29.1
Turkey	30.8	30.3	29.6	27.4	26.5

Source: Authors' compilation.

The reasons are perhaps the size of the market, as well as the degree of protectionism in car imports, along with the presence of vehicles from abroad through FDI, but also especially, the ability to apply R&D outputs to domestic automotive manufacturers and increased self-sufficiency in terms of imports of key innovative services and components [11]. In this case, it is appropriate to provide the example of a smiling curve (Figure 4) that clearly explains the share of added value.

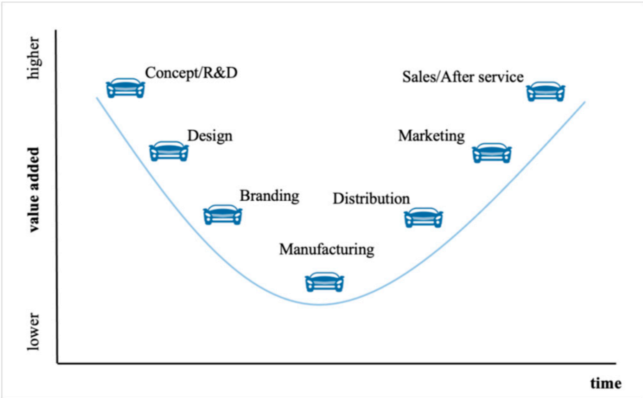

Figure 4. GVC in terms of added value (individual processes). Source: Authors' compilation.

4.2. Opportunities for Value-Added Growth

Simple conclusions about the created competitive advantage can answer the question of how to increase the added value of the automotive industry [47,48]. In Japan, the quality supply of labor is considered a source of innovation. With this in mind, a level change in the value chain in favor of creating higher added value can be achieved in four ways by shifting the strategies in global value chains [15]:

1. Process upgrading: Evolutionary changes and higher process efficiency (e.g., handicrafts in Guatemala, which compete with products from Asia);
2. Product upgrading: Changes to the product portfolio to increase the added value (e.g., coffee industry);
3. Functional upgrading: Application of activities with a higher rate of added value: research and development, sales/services, design, and marketing (e.g., Mexico and its methods for the production and export of jeans);
4. Interchain upgrading: Changes in the production base of companies that will allow entry into new global markets (e.g., Taiwan and its approach to computer production).

Most authors acknowledge the difficulty of establishing and shifting global value chains today, pointing to the uncertain outcomes, as long-term leaders in the sector protect their patent rights and, therefore, maintain their positions as traditional industry leaders, continually increasing their market shares [27].

The transfer of technological knowhow to parent companies is one of the solutions. This will enable better cooperation between local companies and production networks while being able to master new business and management practices, organizational structures, and, in particular, learn to continuously adapt to technological improvements. The main source of the shift in industrial value chains is innovation policy, which removes barriers that affect research-based companies (number of patents). Economic research [29] points to the other side of this effect, i.e., transferring investment support expenditures (e.g., science and research, scientific skills and capacities, publication outputs), which may lose their effect. There is a need for stronger coherence of innovation policy with specific companies. Approaches to increasing the value-added in terms of the implications of Industry 4.0 are presented in other parts of this subchapter.

Information technology has already simplified human-to-human communication, later human-machine communication, and can now help with machine-to-machine communication. Development of this type can pave the way for continuous, higher automation through a large number of communication channels and digital control systems. The moment sustainable manufacturing via the IoT is added to machines, a fundamental change in industrial production is achieved: moving from the physical to the cyber-physical, to a fully digital environment [49,50]. The most advanced technologies began to be used in the field of logistics and in production and storage management facilities, which created digital factories (production plants with high efficiency and a very low level of error) developed on sustainable industrial big data.

Industry 4.0-based smart factories are a standalone system that is digitally connected via the IoT and automated production processes. Importantly, however, cyber-physical system-based manufacturing integrates hardware, software, and technological processes, making them more adaptable, independent, and decentralized in smart networked factories. As a result, the time from production to the sale of products will be shortened. Permanent interconnection in the digital society and integration of product life cycle data throughout the supply chain enable new products to save resources and consumers to benefit from better services, as well as ensure their continuous innovation and improvement by deploying IoT sensing networks [51].

With each step of production and real-time process monitoring, manufacturing big data is created and acquired through the use of artificial intelligence-based decision-making algorithms, instrumental both in real-time analysis and post-production analysis. Digital factories, by leveraging artificial intelligence data-driven IoT systems, will be able to manipulate and analyze data and turn those into information that can be used efficiently and cost-effectively throughout the product lifecycle, from the idea, through product lifecycle management solutions, to the design and production, up to delivery, service, and disposal [38].

Permanent use of networked information and knowledge can dynamically integrate customer requirements throughout the supply chain. This will make it possible to react flexibly to changes in raw material prices and demand volumes, and also to minimize energy and material consumption. On the other hand, it will support efforts to maximize sustainable development in the environment, along with health and safety [35].

The onset of sustainable Industry 4.0 wireless networks is directly linked with the issue of product design, which has a marked effect on personalization and meeting the individual needs of customers. Computer-aided design (CAD) technology is a system that uses virtual and augmented reality and simulation in design. Through CAD, the condition is significantly improved and products reach factories before their actual manufacturing. The result is a product with high quality, a minimal error rate, and easy adaptability (repetition of design processes) [52]. Laser-precision tools, for first-rate design, functionality, and appearance, will create solutions for computer-aided manufacturing (CAM) products. Through these solutions, it will be possible to shorten the production and eliminate excess waste. This technology is considered a potential tool for the Slovak industry, which can transform it from reactive to proactive and from local to global [12]. The smart industry is an incremental process in industrial activities that integrally configures information into knowledge and transforms it into competitive products [53].

On the other hand, it is very important and necessary to solve the high dependence of Slovakia on raw materials so that they do not become the most expensive component of the production process. For innovators and processors, this will mean finding a solution to make the industry more competitive. New potential materials will play a key role in cost-effectiveness and resource efficiency. In terms of supply chain interconnection, communication needs to be improved, making planning easier and helping consumers react to emerging events in real-time. Advances in sensors, hydraulics, and mobility could lead to a new generation of cooperating robots (co-bots) in the processing sector. This could completely change the division of labor between man and machine [54].

Competitiveness and growth in the digital economy can streamline collaboration between elements of the digital environment with a view to digitized mass production, enabling better levels of communication and transparency in global supply networks.

Standardization is key to the growth of interoperable technologies, as well as to e-commerce solutions and platforms [37]. Future development of standardization will enable support for new and more efficient digital services and cooperation between companies. Cyber-physical smart manufacturing and IoT-based real-time production logistics will become the cornerstones of the horizontal integration of the existing data-driven platforms and reconfigure industry-wide supply chains into supply networks, thereby reducing the fragmentation of the Slovak and EU markets through big data-driven decision-making processes [55].

Creativity is also pivotal in the field of digitization and innovative technologies. It is a process where the design becomes more important than the technology itself, the production process, or the final product. The importance of the creative industry can already be perceived when looking for creative ways to improve the user or operator experience (e.g., virtual reality). The ecological and compatible sides of the product, with other manufactured items, can be enhanced through intelligent (eco) design [56]. The right combination of proven technological concepts and cutting-edge technology with out-of-the-box and creative thinking, embedded in an engaging work environment, creates an intelligent and enjoyable experience for the end-user [27].

This process may already be followed in Slovakia. A constantly growing branch of creativity, in combination with business services, represents almost one-third of the exports of services from Slovakia. The potential for this area is coupled, however, with the challenge of creating new, small businesses, developing existing companies, and enabling the creation of new jobs with high added value [29].

Research and development in information and communications technologies, cybernetics, and industrial artificial intelligence are the main features of smart manufacturing, which will enable a sharp increase in added value. Research and development in Slovakia must be subject to changes that will ensure higher expertise, critical research capacities, and, last but not least, sufficient funding [12]. It is important and necessary to network applications and research centers, with the possibility of using the already existing scientific and development infrastructure in Slovakia. These networks should lead to international cooperation, according to certain models such as Fraunhofer or VTT (Technical Research Center of Finland). Startups and innovative small- and medium-sized enterprises for creativity and non-standard solutions should be involved in the network.

Rich and developed countries invest significantly in research and innovation. [57]. This includes the need for a new concept that will necessitate engagement with smart technologies on both sides (production and consumption). The essence of the concept is to create so-called smart grids in Slovakia as a key technical solution for the development of the electricity system [20]. The electricity system will enable the integration of smart concepts not only on the generation side (connecting renewable energy sources and other low-carbon energy sources) but also on the consumption side, where consumers are more significantly involved in the energy market system (e.g., smart homes, smart technologies for consumers, artificial intelligence-driven management mechanisms, intelligent buildings), as well as the introduction of electromobility [24]. Technologies are the trigger for innovation and productivity in business, industry, and many other sectors. For the end-user, this will mean operational efficiency and lower costs. Humans and machines will be able to send information in real-time through interconnected application networks. This will allow them to synchronize quickly and efficiently [4]. This type of equipment capability will represent high potential for industry, whether in the processing, architecture, healthcare, infrastructure, or transport sectors. The cooperation of these industries, together with technological components, will make it possible to create an efficient, productive, and ecological environment for citizens—a smart city [11].

The most advanced intelligent transport systems, telematics, and multimodal integration will provide support for cities in terms of increasing mobility, reducing emissions, and personalizing the user experience. Transport systems under Industry 4.0 provide the basis for the proper functioning of the smart city concept, which supports the overall integration of technology and communication into a strategic and sustainable approach [15].

4.3. Results of the Questionnaire Survey and Identification of Trends

The next section was compiled based on a questionnaire that was created with input from employees of Industry 4.0, sustainable, cyber-physical manufacturing systems, and enterprises that had digitalized their manufacturing (four enterprises, about 80 individuals).

In response to the first question, the respondents reaffirmed the significance of Industry 4.0 for practically all Slovakian industries as well as their expectations for the sector's development at the national level, especially when viewed from a long-term perspective. Implementing this idea and addressing it at the national level are crucial since innovation and spending on research and development can advance the Slovak economy and industry [46]. The concept of Industry 4.0 is important for the Slovak industry because the automotive sector dominates the national economy, integrating intelligent transportation applications, connected vehicle technologies, and big geospatial data analytics. The IoT connection will allow connected devices to communicate with one another more quickly and effectively. The entire pool of devices will work together and interact with one another, making them intelligent. The network will be able to synchronize and receive numerous requests, data, and "orders" in real-time thanks to cloud and big data applications. Faster communication is made possible by digitization, which reduces wasteful use of paper and other consumables. As a result, there are fewer product errors, more control, and a more seamless production process [4].

Concerning the second question, in Industry 4.0, a company needs to understand the need to produce better and higher-quality products, more efficiently, and with fewer product errors. In the case of PSA Group SVK, which partners with the fourth-largest carmaker globally, Stellantis, innovation appears to be essential for the future. The company's capability for innovation will increase even further as a result of this collaboration and increased capital expenditures. PSA has recently dominated within the InoLab division, which works with the Industry 4.0 idea. Its primary goals are: creation of automation-based manufacturing and logistics solutions; digitalization of businesses; fostering collaboration with universities, tech firms, and government agencies; administration of EU funds, contributions, and awards; collaboration with college students from French and Slovak universities.

Another crucial aspect of this transformation is preparing students and employees through education and training. Business management views digitalization as a better, more thorough, and quicker interconnection of goods, suppliers, customers, and automakers, articulating a digital supply chain. In manufacturing, production line and machine employees' communication is currently becoming digitalized (it has replaced paper production). Naturally, not everything has been digitalized yet; it takes time and effort, but soon, big changes will be feasible. Several respondents cited the importance of employee training, constant staff training, and retraining.

The organization has been familiar with these ideas for a number of years, particularly the Industry 4.0 department, which employs them frequently and views them as crucial components of production under the Industry 4.0 concept. They see cybernetics and artificial intelligence as a system intended to ensure that production processes interact with one another and share information, which will result in unit autonomy and task optimization [18].

For instance, the car producer in Trnava dominates the market with its first-rate infrastructure and has the potential to rank among Slovakia's most creative businesses. It also views its location in Slovakia's west, which is closely connected to all modes of transportation, as a strategic advantage in terms of distances to important suppliers and innovators. Additionally, it offers continuing staff training, dual enrolment, and a comprehensive approach to collaboration with colleges. It spent 78,000 euros on 63,567 h of labor in 2020, including both agency and regular staff training. One of this organization's biggest roadblocks to becoming a digital and inventive corporation is the unrealized in-house research and development. It must quickly complete research and development to improve the innovation process. Respondents view this company's level of preparation for the shift to a digital world as partial. Following the merger with Stellantis, PSA Group's vision and plans, which include the production of more high-quality cars and electric vehicles in the future, have become more solid. PSA Group has nearly completed all of its steps and set out its strategy. The development of PSA Group SVK pilot projects is carried out by InoLab, a company that deals with many different technologies. One example is the virtual reality for creating a car and its components. This business is a pioneer in employee retraining. As was previously noted, more and more businesses are making annual investments in their staff, particularly in education. Perfect data analysis, an additional step, is where the company notes important changes, particularly in supply structures. PSA Group SVK became a digital enterprise by necessitating that an idea is accepted by everyone involved in the entire production process, though obviously not at all levels. Additionally, it is a part of the ecosystem, and Slovakia's environmental policy is among the most cutting edge. It adheres to the environmental management standard ISO 14001. The business respects the storage requirements for chemical goods and abides by stringent restrictions on the release of wastewater or emissions into the atmosphere [58].

All activities in these businesses are digitalized, according to the questionnaire's answers. This mostly concerns digital interactions with suppliers and the full supply chain. It then includes product technical preparation, where paperless production is helpful, and customer contacts, which are also handled digitally [59].

The primary functions of assembly lines within businesses, like the creation of automobiles, are the key areas of attention for automation. The company was able to adopt a number of innovations that have improved the efficiency of its operations during the release of the new generation of PSA automobiles, such as the 208 (full kitting, laser geometry control, 675 robotic arms, edge supplying). These automation components are primarily the focus of PSA Group Slovakia (Figure 5).

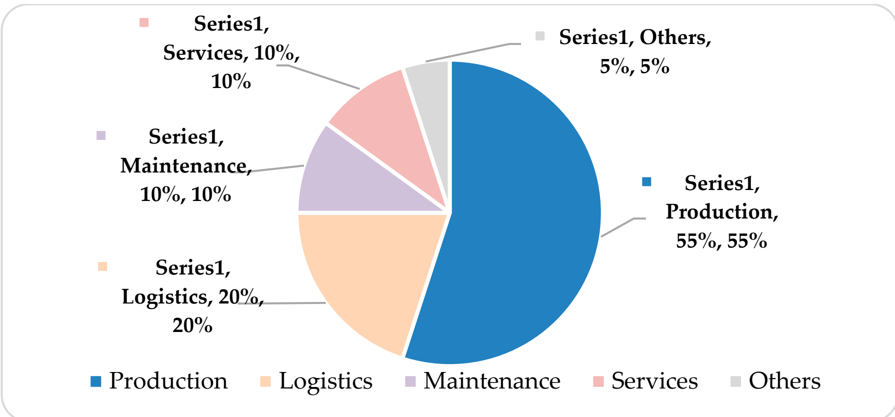

Figure 5. PSA Group SVK automation areas. Source: Authors' compilation.

It is confirmed in Figure 5 that automation dominates manufacturing to the tune of roughly 55%. The major topics here are laser technologies and robotic processing (675 robots). Maintenance and services come in second with a 10% stake, followed by logistics with a 20% share. The remaining 5% are different tasks, but the majority (95%) are automated core solutions [58].

As can be seen in Table 6, the company's annual car output has climbed by more than 25% on average. Brand-new Citroen C3 and Peugeot 208 vehicles were created in 2020. There were about 338,050 automobiles made in total. Production increased by about 35,032 automobiles from 2015 to 2016. The company primarily produces batteries and works with electric vehicles (33,334 electric vehicles were produced). As the business transitions to a totally digital environment, there is a noticeable growth in digital communication networks from machines to customer structures, demonstrating the impact of the present e-mobility trend by more than 50%. The corporation has also digitized its paper-based production, increasing the volume of production data in the process. Additionally, businesses, particularly PSA, have shifted their attention to other investments over time [45]. Selected investments broken down by years are as follows:

- 700 million euros were invested in the building and beginning of production of the first Peugeot 207 model;
- 100 million euros were invested in the Citroen C3 Picasso's manufacturing introduction;
- The annual investment to begin Peugeot 208 production was 120 million euros (2011);
- 80 million euros was invested to launch the new Citroen C3's production (2015);
- 100 million euros was invested to launch manufacturing of the new Peugeot 208 and e-208 (2018).

Table 6. Production of cars in PSA Group SVK (10 years).

Year/Model	Peugeot 207	Peugeot 208	Citroën C3 Picasso	Citroën C3	NG Peugeot 208	Total Production
2011	109,219	82	68,375	0	-	177,676
2012	45,576	113,532	55,509	0	-	214,617
2013	-	184,740	63,671	0	-	248,411
2014	-	206,562	48,614	0	-	255,176
2015	-	259,388	43,630	0	-	303,018
2016	-	236,691	35,525	42,834	-	315,050
2017	-	82,445	17,677	235,174	-	335,296
2018	-	111,251	-	240,744	87	352,082
2019	-	80,947	-	234,443	55,762	371,152
2020	-	-	-	178,276	159,774	338,050

Source: Authors' compilation.

More than 1.2 billion euros have been invested in Slovakia by the group as a whole (Figure 6).

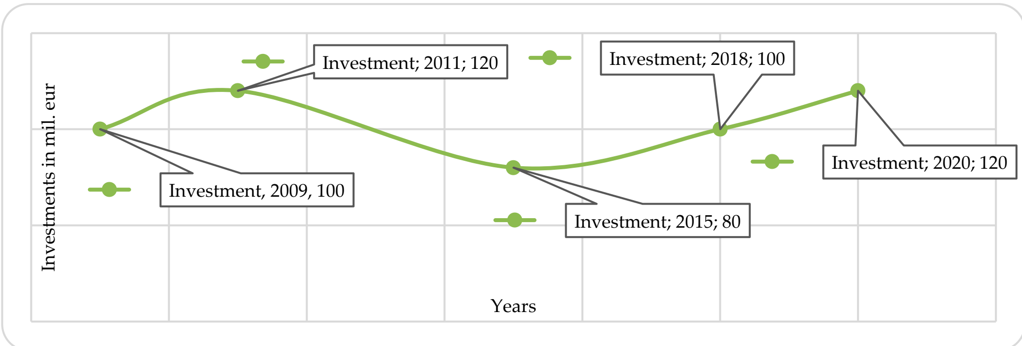

Figure 6. The most impactful investments of PSA Group SVK. Source: Authors' compilation.

The enterprise currently makes significant investments in the environment and electromobility (battery manufacture) (over 20 percent compared to last year). It creates initiatives and technology in fields including automated logistics systems, laser solutions, and others.

Another contentious issue is whether or not shortening the product innovation cycle has been successful. Recently, the company's whole production was halted as a result of the COVID-19 pandemic. A shorter invention cycle is also debatable given the current energy crisis and the ongoing chip shortage. The corporation can use methods to speed up the innovation cycle of the production process once it has the necessary data and a sufficient supply of raw materials. Examples include production environment analyses or Six Sigma (define, measure, analyze, improve, and control) [40].

To register finished goods at PSA, vehicles must be recorded as they leave the final manufacturing line and proceed to the warehouse from which they will be transported.

Another employee steps in at this point and makes a physical record while also marking the finished model with a reader device (electric form and communication totem).

Employees might retrain in many different ways to acquire the necessary skills. As was previously stated (PSA), 63,567 h, or almost 178,000 euros, were spent on staff training and development in 2020. This, in particular, included:

- Industrial automation and robotics technical training (Boost school);
- Legislative education;
- Mastering the English language;
- Simple operation and assembly skills;
- The first round of training for new hires.

To improve the industrial automation and robotics competences of maintenance staff in manufacturing plants, the corporate project "Boost School AUT/ROB" was started in 2020. At the moment, 49 PSA Group SVK students are enrolled in dual education through the project.

All businesses today are driven by electromobility; in 2021, 33,334 of the total number of manufactured vehicles had the e-208 monogram and were electric. The battery manufacturer finished 35,922 battery packs last year. The start-up costs for the Peugeot 208 and e-208 of the next generation came to 100 million euros (2018). In Trnava, the first battery assembly plant was also set up.

One of PSA Group Slovakia's most recent Industry 4.0 breakthroughs was the establishment of InoLab in 2020, which accelerated the shift to paperless manufacturing and a digital supply chain. Additionally, investments in laser welding and complete kitting were made, as well as a building for the manufacture of batteries. The PSA Group's quietest press shops, laser geometry control, environmentally friendly paint shops, and predictive maintenance technologies are also noteworthy.

"PROCE55" is a cutting-edge, agile piece of software for Industry 4.0 mobile maintenance management. It delivers an online overview of production, reliable and unbiased machine data, and system integration. High adaptability to particular innovative techniques dominates. By speeding up production, improving quality, and bolstering post-production product control, Industry 4.0 innovations can dramatically streamline the manufacturing process. The business uses a plant quality indicator (DVT) to find problems [59].

The process will quicken and become more significant as people become more interested in electric vehicles. The Industry 4.0 staff unanimously agrees that using advanced sustainable intelligent transportation systems, computer vision algorithms, and deep learning-based sensor technologies will have a substantial impact on the automobile industry, particularly in Slovakia, by leveraging smart sustainable intelligent transportation systems, computer vision algorithms, and deep learning-based sensing technologies. Yet, their application and potential to become the standard are uncertain. They also emphasize the significance of supporting legislation, education, research, and development.

At the moment, from the standpoint of Industry 4.0, PSA Group SVK has obtained funding for a new sector B production program at its Trnava manufacturing facility (2021). For sector B, a new production schedule will gradually begin in 2023. A major portion of the production program will be made up of entirely electric motors to greatly increase carbon neutrality. Industry 4.0 technological application, innovation, energy intensity reduction, and environmental protection will all see considerable increases as a result of the new production program's industrial investment [45]. Of course, the business has employed them, but to a limited extent (for example, EU funds for employee training).

Industry 4.0 will undoubtedly increase competition, reduce costs, reduce stockpiles, and increase production efficiency [60–65]. The potential loss of some job positions was mentioned by respondents as a drawback (risks). They also affirmed the urgency with which this concept must be put into practice, particularly in light of the increased rivalry from nearby nations.

The Industry 4.0 idea has a favorable impact on the exports of the vehicle firm by setting up intelligent, digital businesses where all production components, equipment, and workers are connected in real-time, resulting in improved production efficiency, fewer mistakes, and decreased production costs. As a result, the corporation can dominate with a larger selection of high-quality products thanks to an optimized supply chain. Additionally, these aspects will benefit its subsequent exports and consumer relationships [2].

According to an investigation of corporate data for the years 2020–2021, it was discovered that the added value of Peugeot 208 and Citroen C3 automobiles spans a number of nations. The parent nation of the business, France (31.06%), generates the most value, followed by Slovakia with a share of roughly 9.5% (primarily assembly labor; see Figure 7). In France, the engineering and design of vehicles incorporate the most recent technologies. The objective must be to maximize the share of Slovak value contributed to the production process and raise this share every year. Yet, Slovakia will never reach the same level of added value as France because it is not the parent country of the enterprise.

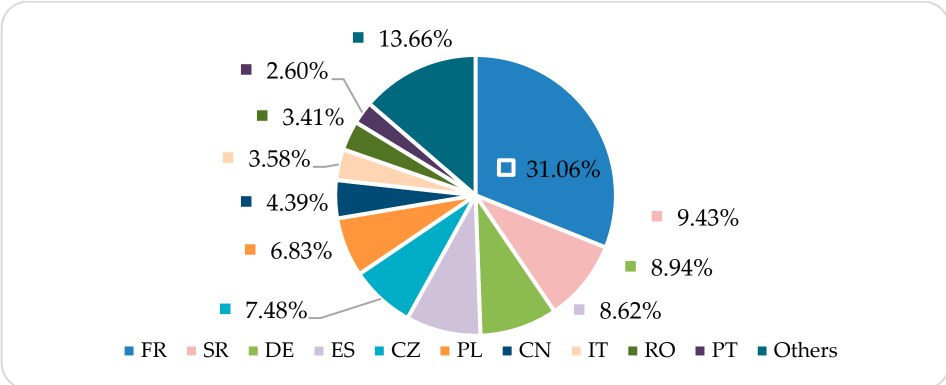

Figure 7. Percentage of value-added for C3 and 208 vehicles by country (2020–2021). Source: Authors' compilation.

The company will increase the added value of its products and make them more marketable by implementing innovations and critical research and development that it does not currently apply at large in Slovakia. As a result, the automaker will become innovative and set the standard for its rivals. Yet, it is uncertain when and how the Slovak government and general legislation will be able to react to this trend to encourage businesses with creative policies, better circumstances, and laws. The unique idea can only become a reality with the cooperation of two parties, specifically the corporation and the government. This is viewed by respondents as a weakness of the Industry 4.0 idea in Slovakia. In comparison to the rest of the world, the legislative environment is now weak and even chaotic in some regions. Only when businesses have the resources to conduct their own research and development will Slovakia experience exponential growth in terms of added value [2].

5. Conclusions

The interconnectedness of the smart industry with current trends and technologies [66–69] pushes the industry to a higher level of awareness and thus represents a benefit. Developed EU countries are already implementing this trend so it is important that Slovakia focuses on the wide range of innovative solutions available.

There is a great need to integrate Industry 4.0 across all sectors. The vision and one of the corporate goals of the Slovak industry is to combine research and development activities with innovation, including broad-based applications [70–73], which will enable all relevant technologies, knowledge, and skills from industry and various sectors to contribute to improving the quality of life in Slovakia. In Slovakia, it is necessary to ensure development in the technological area, especially in the automotive industry, due to the advent of intelligent production in Industry 4.0, by harnessing deep learning-based sensing technologies configuring smart sustainable urban mobility behaviors, networked transport systems, and intelligent vehicular networks. For Slovak carmakers to remain globally competitive at the end of this decade and beyond, eco-innovation should be a top priority for the national automotive industry.

Since the advent of digitization, companies have been promising a highly pre-competitive market share [74–77] and productivity growth. Through surveys results, it is possible to observe an increased share of companies that expect stronger resilience to future crises from Industry 4.0, especially given the COVID-19 pandemic. In a sense, it is possible to characterize a pandemic as a kind of accelerator of higher automation and digitization in companies.

The present study mapped the implications of Industry 4.0 for the structure of international trade [78–80] and changes to the organization of global value chains [81–84], to characterize the key opportunities of these value alterations for added growth [85–88] in automotive industry exports. Despite the robustness of the analysis, however, the study has certain limitations as it was conducted in one country and there are currently unavailable data. On the other hand, the social, economic, and cultural environments, and especially the legislative environment of national economies, also play important roles in the implementation of Industry 4.0. A comparison of Industry 4.0 implementation in the automotive or other key sectors within the Visegrád countries or throughout Central Europe is an aim of our future research.

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