Chapter

Management of Innovation Performance on the Example of the Automotive Supply Chains

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Abstract

The chapter presents original research showing the relationship between expenditures on developing systems (including IT) supporting innovation management of supply chains of three international automotive companies and their innovation performance. A novelty in comparison to previous (cited) studies is that the calculated correlation coefficients show the significance of the link between the expenditures on components of the suppliers' innovation management system, that is, expenditure on the improvement of innovative competences of suppliers, and the expenditure on ICT, and innovation performance of automotive companies. By establishing data interdependence, elements of the management system that contributed the most to improving the innovation performance of three international auto motive companies over the past years were selected. Analyses of data may facilitate the management of expenditure on: internal R&D activities and support for external innovators. In this chapter, the author used the results of her previous studies. To collect additional data, the following methods were used: review of documents and diagnostic survey (technique: survey, tool: questionnaire). To analyse the data obtained, a statistical method and computer simulation methods were used. The research was based on quantitative secondary data[1] and estimates (given by respondents from the automotive companies as a percentage of a specific value contained in official documents). The data for the analysis came from publications and surveys.

Keywords: R&D, supply chain management, sustainability

1. Introduction

The supply chain will be understood as a group of companies that are suppliers and customers of each other. There is a flow of goods, information, knowledge, resources, funds, and innovative solutions between companies. The company that takes on the challenge of managing the supply chain is referred to as a leader or an integrator.

The innovation performance of companies that cooperate in supply chains may be increased by cooperation in three different dimensions: new technologies, new

[1] http://iri.jrc.ec.europa.eu/scoreboard.html

knowledge and skills, and new forms of cooperation [1]. To develop innovations in the open model (OM), the company that manages the supply chain (the leader) should incur expenditure on the following:

- R&D activities carried out together with suppliers
- Suppliers' innovation development programmes
- ICT implemented in order to streamline innovation development processes with suppliers

Making decisions on the amount of expenditure should be justified by statements on the sustainable development of supply chains and backed up by research. This paper presents the research (including research tools) and the results that facilitate decision-making.

The article confirms the thesis that the greatest automotive innovators develop new products with the use of the open innovation model (OI) and manage the innovation performance of their supply chains. Automotive companies are in need of the implementation of tools that support innovation productivity management (e.g., in order to optimise expenditure on the development of the open innovation model).

The basic objective of the article was to verify the usefulness of the research tool empirically, which-following adjustments-could be used in the practice of the innovation performance management of automotive companies and their supply chains.

The subsequent chapters of the paper analysed the development of measures of innovation performance and their application. There was a gap in studies concerning the measurement of innovation performance of cooperative companies. The studies that showed the importance of managing relations and resources of cooperative companies in the increase in innovation performance of supply chains were cited. Another research gap was identified. The researchers did not measure expenditure on the management of relations and resources of cooperative companies or expenditure on ICT tools that support such management in terms of their own innovation performance.

The article contains original research showing that the increase in expenditure on innovation management of suppliers results in an increase in the innovation performance of the leader in the supply chain. The analyses confirming this relationship are based on data on automotive companies, which have been at the forefront of the most innovative company rankings for years. The obtained results are new. Previous researchers showed that suppliers' management contributes to the increase in innovation performance. The presented research confirms this on the basis of data from three international companies, originating from different cultures, and thus differently managing relations with suppliers. It shows that even the surveyed companies (the world's greatest innovators) are struggling to implement a sustainable suppliers' development policy. The author believes that the results of this research will facilitate making investment decisions in the R&D activity and will lead to the transition to an open model of developing innovations together with suppliers. The author calls for the collection of data and the use of ICT for the analysis of expenditure on research and development. She proves that currently the data are scattered and inconsistent, which are, therefore, difficult to process. Finally, she postulates the preparation of a systemic model for the supply chain innovation management.

2. Measurement of innovation performance of enterprises

Innovation management can be defined as systematic planning, organising, implementing, and controlling activities carried out to develop and introduce new products and related processes [2]. In the literature, innovation management comes down to a management process consisting of the following three stages:

- Ideation, which refers to the very process of generating ideas and includes recognition of opportunities, analysis, generation of ideas, evaluation, and selection, as well as product concept creation [3].

- Development, the stage of new product development (NPD) or new service development (NSD), including calculating, modelling, and prototyping. A typical NPD process is presented in the Cooper Stage-Gate [4] model.

- Launch, at this stage the company is involved in the production and distribution, marketing, diffusion (e.g., licensing), learning, and getting experience from the project [5].

The ideation stage has a significant impact on the entire process of innovation [6]. The main result of this stage is the concept of a new product, which can then enter the formal process of technological development.

Difficulties in the management of ideation processes result from the scarcity of developed supporting instruments. Despite the rapid development of information and communication technologies (in particular search engines and computer databases), which significantly improves the process of searching for information, the actual emergence of an idea is still considered mainly an uncontrolled ad-hoc process [7]. In contrast, in the final stages, the engineers have many supporting tools for prototyping, such as CAD/CAE systems.

Idea generation sessions tend to be performed in groups rather than by individuals. Therefore, it is possible to identify a clear need to develop tools to facilitate the process of creating ideas. Innovation management tools are of interest to both companies and researchers. The objectives of innovation management are evolving: it is no longer about introducing innovations by an individual enterprise but about the transformation of innovations in an open model. Innovation has also ceased to be the result of a sequential process [8]. The new model has become a model that is comprised of one leader but is based on feedback from research activities of various companies. The researchers distinguish three models of innovation management, that is, a model of sustainable activities, network model, and a triple helix model [9–11].

a. The model of sustainable activities of the organisation was developed by the Japanese in the 1980s. In this model, various functional units of the company carried out simultaneous activities for the purpose of innovation development.

b. The network model, in which innovation is created through the process implemented by networked enterprises and the development of innovation is guaranteed by strategic alliances of research and development departments of various companies.

c. The triple helix model proposes the development of innovation between governmental organisations and universities [12–15].

The research showed that defining innovation management models differs fundamentally between individual companies and sectors. Automotive companies, which had so far generated innovations in their own functional units, now face new challenges. They are now trying to develop innovations in the open innovation model (either in the network model or the triple helix model).

The two-dimensional concept of measuring the effects of the innovation management model [16] introduces the concept of innovation performance (or innovation), defining it as: the quantity and quality of innovative ideas and the effectiveness and efficiency of implementing these ideas. The above-mentioned parameters of innovation performance can be examined independently and interdependently.

The analysis of innovation performance requires clarification of indicators (measuring the quantity, quality of ideas, and effectiveness and efficiency of innovative processes), selection of methods for their research, and identification of elements (variables) affecting the performance of innovation. This analytical effort leads to understanding and improving the functioning of the innovation management model.

To prepare for the analysis of innovation performance, a literature review was conducted in order to search for indicators, methods, and dependent and independent variables. According to the review [17–19], the innovativeness of companies is most often measured by expenditure on research and development and the number of registered patents. These are conventional indicators (still eagerly used due to their availability). Over time, these indicators have been criticised in the literature as having many disadvantages, and enriched or replaced by survey indicators (developed by the OECD and Eurostat). The quality of the proposed innovative solutions is measured by added value (economic, market, ecological, and social). The effectiveness of research and development processes is based on the number of implemented and commercialised product innovations and length of cycles of product innovation implementation. The effectiveness of processes is most often measured by the profits generated during the sale of innovation and the durability of innovation. If the researcher uses all of the mentioned indicators, they apply the so-called Inex. The applied innovation performance indicators of enterprises in the published studies are shown in **Figure 1**.

In the study of innovation performance, terminologies and methods adapted for this purpose by researchers [19–22] are used most often. A limited number of researchers focus on the study of the relationship between the company's innovation performance and the cooperating companies' innovation performance (For this purpose, statistical methods are used by few researchers). Authors using statistical methods most widely used multiple regression techniques, the least squares

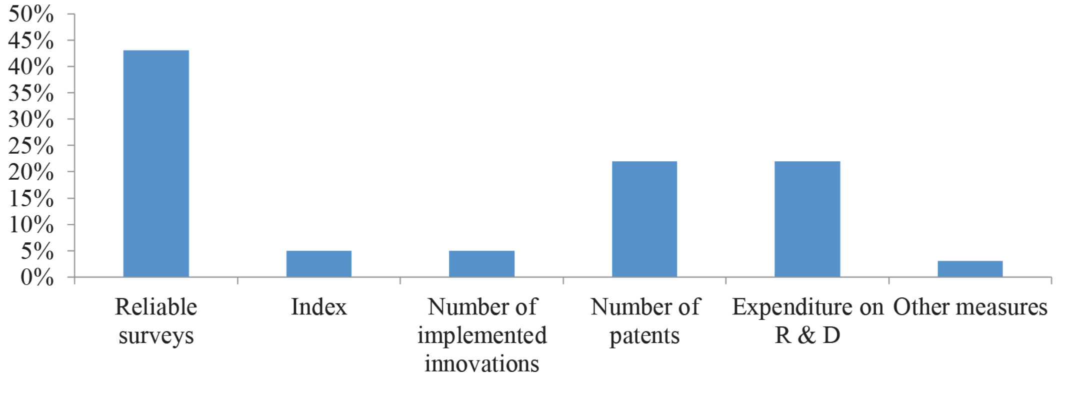

Figure 1.
Applied innovation performance indicators of enterprises [19].

method, logarithmic methods, and probit models (39.3% of the analysed studies used these methods). The researchers also used other statistical econometric methods (23.8%), such as factor analysis, cluster analysis, principal component analysis, count data models, and stochastic border analyses [23].

In 1998, the groundbreaking article "Research, Innovation, and Productivity: An Econometric Analysis at the Firm Level" by Crépon, Duguet, and Mairesse was published. In this article, the researchers created an empirical framework called CDM (the acronym of the three authors' names) or Mairesse Model. The framework is used in almost every study on innovation performance [24]. The CDM has inspired other researchers who over the years have proposed many variations of the original CDM model depending on whether they use continuous or discrete data to study innovation, different output measures, and different estimation methods. The original cross-sectional model has been expanded to include panel data, dynamic models, and applications for many types of innovative activities and indicators such as economic performance, that is, profitability or productivity of the enterprise.

As mentioned, the analysis of innovation performance cannot be deprived of a review of dependent, independent, and the so-called contextual/conditional variables. The literature lists those variables that affect the innovation performance of enterprises. Among the contextual variables, cooperation in the supply chain is listed first. Therefore, in the next chapters of the article, innovation performance will be presented in the context of using suppliers' resources from the supply chain.

3. Management of relations and resources of cooperating companies: the role of the integration platform in shaping the supply chain and increasing its innovation performance

The necessary factors for obtaining high innovation performance of a company integrating the supply chain are optimally selected resources and competences of individual participants in terms of quantity, quality, and cost, adequate flow of data, information, and knowledge, supported by appropriate IT tools [25, 26].

Standard registration systems or a database easily subjected to analytical processing are no longer sufficient. Business intelligence tools equipped with knowledge of resource theory, dominance, and network approach are needed, as well as tools testing different theories on the basis of many paradigms, drawing from the literature classifying management paradigms. On the basis of the network paradigm variables, six basic outsourcing models were built at the University of Tennessee, which dominate in the twenty-first century [27]. One of them is the vested outsourcing model, which postulates the transition from a traditional business model, oriented to a buy/sell transaction, to a result-oriented and value-added model, in which all business partners benefit. Business intelligence development work is based on this model-supporting innovative management in the supply chain.

Innovative websites and integration platforms based on the vested model are being introduced. One such platform is the Jabil Supply Chain Operations Center. The platform can simulate the supply chain from the first to the last link in real time. The system identifies high, medium, and low risk flows in the supply chain, as well as the possibilities of their optimisation. It provides supply and processing of data on the resources of individual enterprises belonging to the supply chain, labour law, taxes, admissibility of goods, political unrest, changing product requirements, breakdowns, and congestion. Jabil Supply Chain can assess all those factors that proactively affect the configuration of the supply chain, optimising it for each customer or for all at once. The chain can be modelled at the beginning of the product life cycle, that is, in the research and development phase (before commercialisation), and in the subsequent phases. The platform can also deepen the analyses of the logistics operations or simulate the shape of a new logistics chain. **Figure 2** presents the architecture of a business integration platform (identifying data sources for analysis, data collection, storage and processing systems, and information that can be generated).

Another example, also known as the new hub for innovation, is the Jabil Blue Sky Center. This platform brings together key experts from around the world (about 350 people) and connects businesses through these people. The world's largest curved touch screen serves the purpose of combining R&D activities, giving the possibility of illustrating a wide portfolio of engineering abilities of users logging in and at the same time stimulating the imagination of the creators of the idea of a new product.

An example of a company shaping its supply chain based on the Jabil Supply Chain solutions is Tesla Motors. Tesla is building a gigantic factory in which batteries for electric vehicles will be produced. Suppliers must participate in this unprecedented scale of production. The supply chain is currently shaped by the platform. Smaller companies specialising in battery technologies can join it. The database located on the platform receives online data from suppliers from around the world (in a predefined standard). For example, REDT (a company producing vanadium flow batteries) understands the importance of a contract with such a large partner so it provides the necessary data. It chose the Jabil database, thus entrusting this platform with confidential technological data and valuable production knowledge, hoping that they will join the Tesla Motors supply chain network [29].

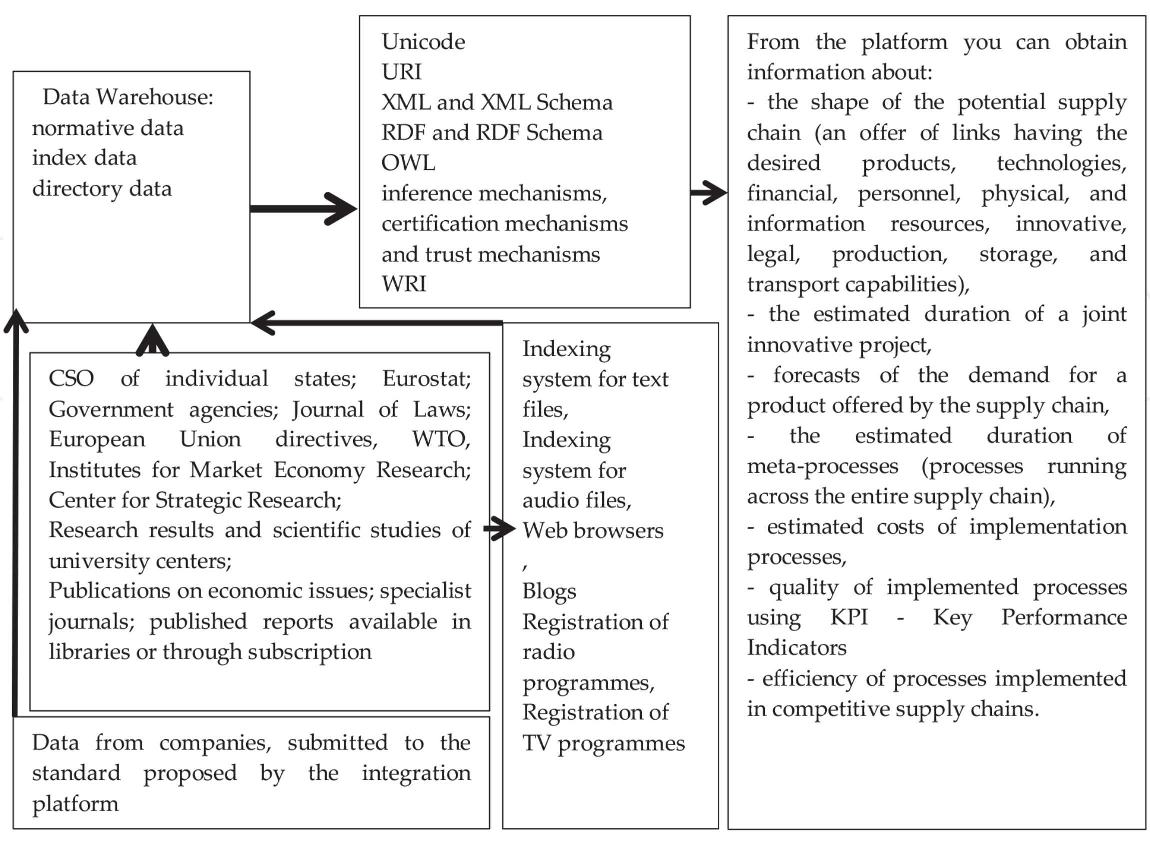

Figure 2.
Architecture of the system analysing the economic environment for the needs of shaping and managing the supply chain [28].

4. Advanced ICT tools for supporting knowledge management in order to increase the innovation performance of the supply chain

Automotive companies implement suppliers' innovation management. They employ managerial methods and tools that shape innovative supply chains and increase their innovation performance. The currently mentioned activities cannot be called systemic because the innovativeness of suppliers and their impact on the integrator's innovation performance is not measured [25–27, 30].

The Toyota company is the closest to a systemic innovation management of suppliers. Among the keiretsu group suppliers, Toyota builds a specific organisational culture and uses the philosophy of challenge, kaizen, genchi genbutsu, mutual respect, teamwork, Toyota Production System, and quality circles. The supplier innovation management system implemented by Toyota is a perfect example of the Japanese approach to teamwork. Decisions on developing products are not made suddenly: they are worked out during many meetings, discussions, and collective consultations in the group of managers of cooperating enterprises. Even if Toyota's actions are not explicitly referred to as a management system, they in fact create an integrated set of rules, procedures, and methods oriented at creating, popularising, and using knowledge about innovations. Toyota includes international suppliers in the development of process and product innovations.

Toyota uses a lot of ICT tools for creative problem-solving, for example, IWB (Innovation WorkBench). The software schematically presents problems, automatically analyses them, and leads users to an abstract solution; IAP (Innovation Assessment Program) is software invented by the United Inventors Association. The software helps inventors, entrepreneurs, and marketing specialists in conducting objective analyses of opportunities and threats for ideas and inventions [31]. Toyota develops innovative car software together with suppliers using the standard open source code. The Automotive Grade Linux (AGL) community in Linux Foundation has built an open source platform. Toyota used the platform to develop an audio and infotainment system launched on the market in 2018 and installed in Toyota Camry.

ICT tools have much to offer in the area of initiating innovations arising in the open model in the automotive industry. Research confirming this thesis focused on the phenomenon of open source free software [32], crowdsourcing platforms [33, 34], and network innovation brokers [35]. Other researchers analysed the contribution of ICT to the ability to absorb knowledge from the outside of the enterprise [36], data mining, simulation, prototyping, and visualisation supporting cooperating enterprises in developing new products [37].

Currently, the software for designing in an open model, based on the Blockchain & Smart Contract technology, is developing intensively. The Networking Innovation Room (NIR) is an innovative model of intellectual property (IP) protection created by a group of enterprises. Under NIR, the use of the Non-Disclosure Agreement (NDA) is proposed as an intelligent contract in which the remuneration is the so-called Wits, a virtual currency based on knowledge interactions [38]. Blockchain is a peer-to-peer platform that uses ICT to track the ownership of generated and transferred assets in an open innovation model [39]. Intelligent inter-organisational contracts are run and stored in Blockchain [40]. NIR controls the values added by suppliers, thus reducing the concerns of enterprises regarding the loss or underestimation of the intellectual property contribution. In the concept of NIR, companies in the SME sector [41] are particularly cared for. Everything that is submitted by companies is disclosed in NIR, timestamped, indexed, preserved, made searchable and traceable, and reported (when cooperating companies require it). An NDA is digitally accepted and can be signed when user enters the NIR. The agreement clearly describes the regime of intellectual property protection and the manner in which the co-created innovation will be protected [42]. The function of the developed application is signing legally binding, intelligent contracts that are produced using artificial intelligence creating a blockchain record path. This process is also called “IP document notarisation”. Inventions, projects, and evidence can be quickly registered and the blockchain certificate will confirm the ownership, existence, and sustainability of the IP. All secured notarial information will remain private thanks to cryptography. Blockchain platforms, with the possible functional composition: PoE timestamp; integrity and notarial confirmations; IP register; content metadata; user authentication; record keeping; access control; licensing; traceability; quotation monitoring; reward mechanisms; own currency; NDA management; register of industrial property; and proof of receipt [40].

Some of the innovations that are being developed require fintech services [43]. It is possible to monitor the workflow throughout the innovative community. The system coordinates agreeing on what each player has to do in the cooperation process, when and what corrective actions would apply, what rewards or penalties are used for achieving/not completing milestones, tasks, etc.

CryptoTech also presents many other cases of the use of intelligent contract in the automotive sector’s supply chains [44].

5. Research methodology–stages, objectives, hypotheses, research model

The first chapter lists the indicators of the innovation performance of the enterprise. Indicators evaluate but there are no such ones that allow the impact of the innovation management of supply chain companies on the innovation performance of the leader to be measured. There are no indicators measuring the impact of the integrator’s influence on the chain links. The basic objective of the research was to verify the usefulness of the research tool empirically, which-following adjustments-could be used in the practice of the innovation performance management of automotive companies and their supply chains.

The second and third chapter looked at ICT methods and tools to help manage the innovation of suppliers. Methods and tools used by automotive companies were recognised and described [cedewu]. The previous studies by the author (carried out with the use of the diagnostic survey method) revealed that Toyota, Volkswagen, and FCA incur expenditure on the development of OI.

The expenditure incurred on the development of suppliers’ innovativeness is not analysed in those studies but it should be monitored in order to optimise it. It is recommended to divide expenditure on the management of the supply into expenditure on the development of suppliers’ competences (expenditures on development programmes) and expenditure on managerial tools using ICT technology. To make the management of supply chain innovation systemic, one should measure the amount of expenditure and draw practical conclusions for making subsequent investment decisions. Meanwhile, the automotive sector (in the automotive companies studied) does not measure suppliers’ innovation or their impact on the integrator’s innovation performance. The system that is proposed does not register its own expenses on the suppliers’ development programme and ICT tools that support the suppliers’ innovation management.

The presented research attempts to record expenditure on the development of suppliers’ innovation. The objective of the research was to determine the correlation of innovation performance and the expenditure incurred on research and development activities, suppliers’ development programmes. and ICT tools facilitating

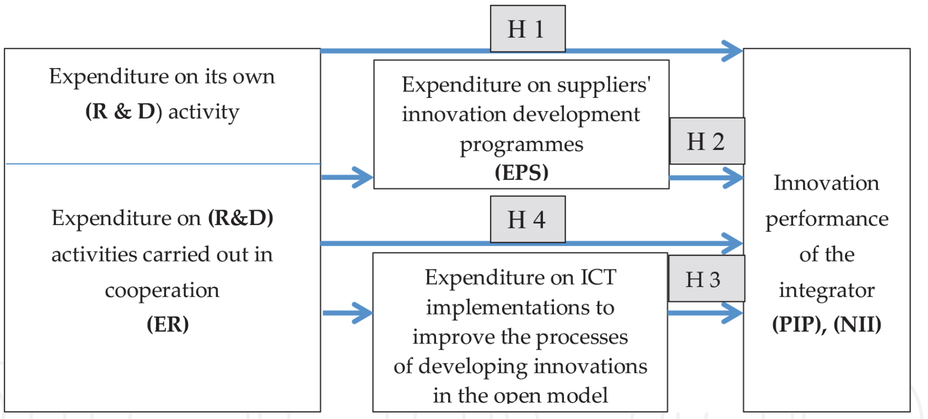

Figure 3.
Research model (source: author's own study).

innovative cooperation with them. The implementation of the research objective allowed for the empirical verification of the usefulness of the prepared research tool, which after the adjustments will be able to be implemented into the practice of managing the innovative.

The implementation of the objective required four hypotheses:

H1. Expenditure on its own research and development activities improves the innovation performance of the company.

H4. Expenditure on research and development in the open innovation model with suppliers influences the increase in innovation performance of the integrator. Increasing expenditure on suppliers' innovation development programmes results in an increase in the innovation performance of the integrator–H2. Increasing expenditure on ICT implementations (improving the processes of developing innovations in the open model) increases the innovation performance of the integrator–H3. The research model presented in **Figure 3** was prepared.

The determination of the relationship between the expenditure and innovation performance of automotive companies took place in the following research stages:

A. The following variables were operationalised:

- Expenditure on R&D activities *in EUR million* (published data).
- Expenditure on R&D activities carried out together with deliveries (ER) *in EUR million* (value estimated by respondents as a percentage of R&D expenditure).
- Expenditure on suppliers' innovation development programmes (EPS) *in EUR million* (value estimated by respondents).
- Expenditure on ICT implemented in order to improve processes of innovation development with suppliers (ECT) *in EUR million* (value estimated by respondents as a percentage of expenditure on CapEx).
- Expenditure on R&D activities for net sales per year (NII) *in %* (published data-Intel R&D).
- Profits generated on innovative products (PIP) *in EUR million* (value estimated by respondents as a percentage of operating profit).

B. A compilation of published data was prepared, which is presented in **Table 1**.

World rank	Company	Country	Expenditure on R&D (€million)	R&D one-year growth (%)	Net sales (€million)	Net sales one-year growth (%)	R&D intensity (%)	CapEx (€million)	CapEx one-year growth (%)	CapEx intensity (%)	Op. profits (€million)	
			2016/2017									
1	VW	Germany	13672.0	0.4	217267.0	1.9	6.3	13152.0	−0.5	6.1	8344.0	3.8
13	TOYOTA	Japan	7500.1	−12.5	224150.8	−2.8	3.3	28764.4	−12.8	12.8	16198.7	7.2
34	FCA	Netherlands	4219.0	2.7	111018.0	0.4	3.8	8815.0	0.0	7.9	5109.0	4.6
			2015/2016									
1	VW	Germany	13612.0	3.8	213292.0	5.4	6.4	13213.0	10.0	6.2	−1228.0	−0.6
10	TOYOTA	Japan	8047.0	5.1	216506.5	4.3	3.7	30941.9	20.9	14.3	21754.8	10.0
31	FCA	Italy	4108.0	12.1	110595.0	15.1	3.7	8819.0	8.6	8.0	2625.0	2.4
			2014/2015									
1	VW	Germany	13120.0	11.7	202458.0	2.8	6.5	12012.0	5.5	5.9	12139.0	6.0
9	TOYOTA	Japan	6858.4	10.3	185940.4	6.0	3.7	22923.4	25.3	12.3	18779.1	10.1
30	FCA	Netherlands	3665.0	9.0	96090.0	10.9	3.8	8121.0	8.4	8.5	3343.0	3.5
			2013/2014									
1	VW	Germany	11743.0	23.4	197007.0	6.0	15.8	11385.0	8.5	5.8	11500.0	5.8
7	TOYOTA	Japan	6269.9	12.8	177017.3	3.5	10.6	18456.2	35.7	10.4	15792.7	8.9
32	FIAT	Italy	3362.0	2.0	86816.0	3.9	34.3	7440.0		8.6	3499.0	4.0
			2012/2013									
1	VW	Germany	9515.0	32.1	193000.0	4.9	22.5	10493.0	29.8	5.4	8333.0	4.3
5	TOYOTA	Japan	7070.9	3.5	193000.0	3.7	5.2	17287.7	28.9	9.0	11567.0	6.0
34	FIAT	Italy	3295.0	51.5	83957.0	3.9	18.8	7534.0	36.3	9.0	3921.0	4.7

World rank	Company	Country	Expenditure on R&D (€million)	R&D one-year growth (%)	Net sales (€million)	Net sales one-year growth (%)	R&D intensity (%)	CapEx (€million)	CapEx one-year growth (%)	CapEx intensity (%)	Op. profits (€million)	
			2011/2012									
1	Toyota	Japan	7754.5	7.6	184,798,1	−1.9	4.2	15235.2	6.6	8.2	3536.4	1.9
3	VW	Germany	7203.0	15.1	159337.0	25.6	4.5	8087.0	−36.7	5.1	10930.0	6.9
52	FIAT	Italy	2175.0	12.3	59559.0	4.1	3.7	5528.0	112.3	9.3	3442.0	5.8

Table 1.
Published data related to R&D activities performed by the surveyed companies [45].

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C. A questionnaire was prepared. The questionnaire is included in **Annex 1**. The questionnaire was sent electronically, using public responder portals of automotive companies. The necessary data were obtained (with the indication that these are only calculated estimates, not supported by a thorough analysis of the finances of the surveyed companies).

D. The obtained data were processed statistically. Calculated correlations and regressions confirmed the hypotheses H1, H2, H3, and H4. Summary and conclusions drawn from the canonical analysis are the culmination of research and confirmation of hypotheses.

The correlation analysis looked primarily at the relationship between (ER), (EPS), (ECT), and innovation performance of automotive companies (NII) and (PIP).

Expenditure on research and development (implemented in the open model with suppliers) (ER), expenditure on suppliers' innovation development programmes (EPS), and expenditure on ICT implemented to improve the processes of obtaining innovations (ECT) were treated as dependent variables. The ratio of expenditure on R&D to net sales (NII) and profits generated on innovative products (PIP) were treated as independent variables. Literature theses were used to confirm the dependence of these variables. The operationalisation of profits from implementations of innovative product solutions was revised [46]. Jałowiecki dealt with the impact of implementing ICT on profits from innovative products [47]. On the other hand, Dzikowski [48] believed that the amount of profits from innovative products depends on the expenditure on suppliers' innovation development programmes. Brem and Tidd [49] believed that the use of a research model as a simulation model supporting innovation management could lead to improved results (independent variables). The use of correlation and regression analysis (on historical data) in innovation management facilitates making investment decisions.

6. Comparative analysis of the innovation performance of Toyota, Volkswagen, and FCA using the research model developed

Figure 4 shows the intensity of R&D in percent, that is, the ratio of expenditure on research and development (in EUR million) to net sales (in EUR million) in the surveyed companies.

Figure 5 shows the intensity of CapEx in percent, that is, the ratio of investment expenditure (in EUR million) to fixed assets (including ICT software) for net sales (in EUR million) in the surveyed companies.

Figure 6 shows the intensity of R&D activities in OI with suppliers in percent (or ER intensity), that is, the ratio of expenditure on research and development made with suppliers (in EUR million) to net sales (in EUR million) in the companies surveyed.

Figure 7 shows the intensity of expenditure on IT systems used to develop innovations in the open model in percent (or ECT intensity), that is, the ratio of IT expenditure (in EUR million) to net sales (in EUR million) in the companies surveyed.

It can be seen from the figures that Volkswagen bears the largest expenditure on research and development in relation to sales, but it invests in ICT (**Figure 7**) with an emphasis on expenditure in the closed innovation model (as shown in **Figure 6**). Toyota, on the other hand, invests in production systems and ICT (as shown in **Figures 5** and 7) and more than other companies invest in research and development in the open model with suppliers (as shown in **Figure 6**). FCA implements expenditure on R&D and invests in systems in a sustainable manner (as shown in

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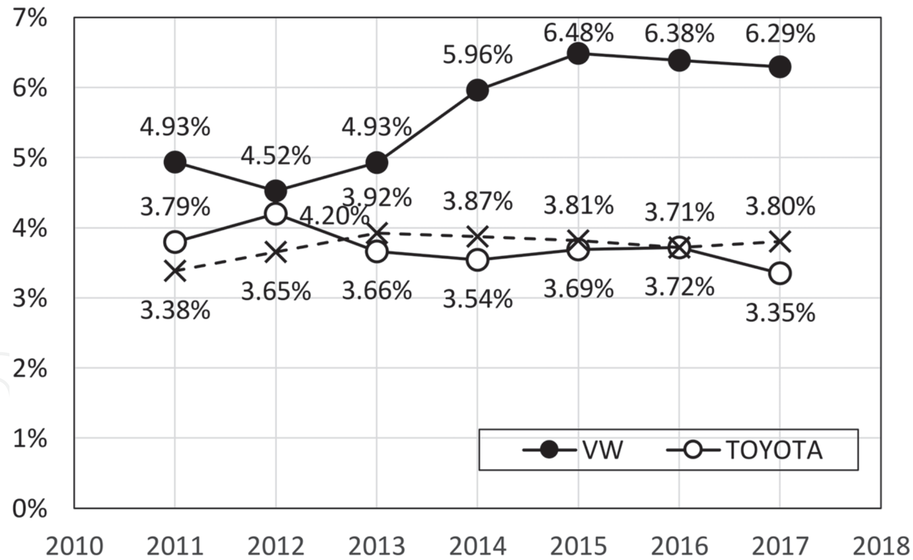

Figure 4.
R&D intensity (%) in the companies surveyed [45].

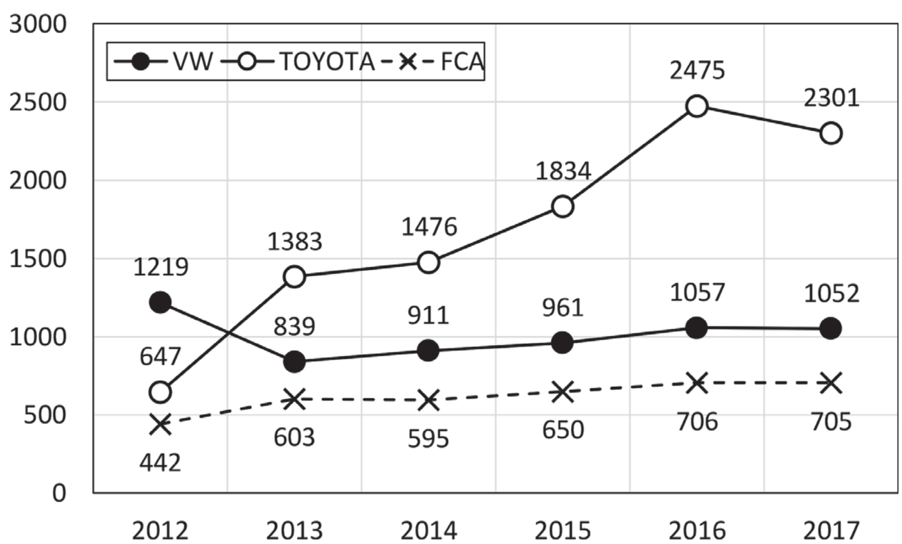

Figure 5.
CapEx intensity (%) in the companies surveyed [45].

Figures 4 and **5**). It maintains a constant trend in incurring expenditure on R&D in the open model (as shown in **Figure 6**).

There are interesting conclusions that can be drawn based on a comparison of changes of investment intensity in research and development over time (**Figure 4**) and investing in research and development but implemented in cooperation with suppliers (**Figure 6**) in Toyota. **Figure 4** clearly shows that the data for this company have a 4-degree polynomial distribution. This is indicated by the high value of the R^2 determination coefficient, amounting to 0.9743 of the theoretical model to empirical data. Such a distribution is rarely seen in practice, with one exception. If the data are a time series and the theoretical model is adapted to its fragment of the appropriate length, it is likely that we are dealing with a time series devoid of or characterised by a negligible trend and clearly marked periodic fluctuations. In contrast to seasonal variations, its amplitude is not 1 year but an appropriate number of periods. In case of changes in the intensity of investing in research and development presented in **Figure 4**, seasonal variations of 5 years are most likely. Of course, the data from the previous years should be checked. Nevertheless, the

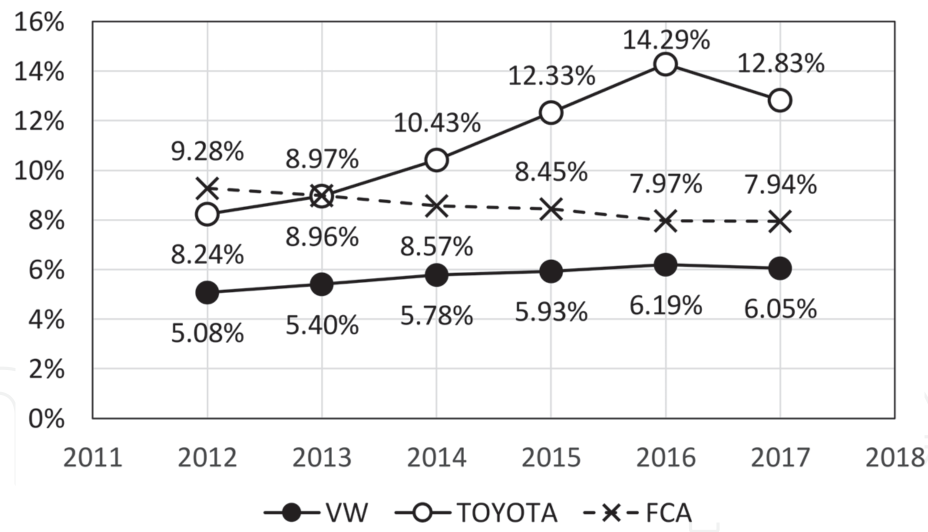

Figure 6.
Intensity of R&D in OI (%)/ER intensity (%) in the companies surveyed (source: author's own study).

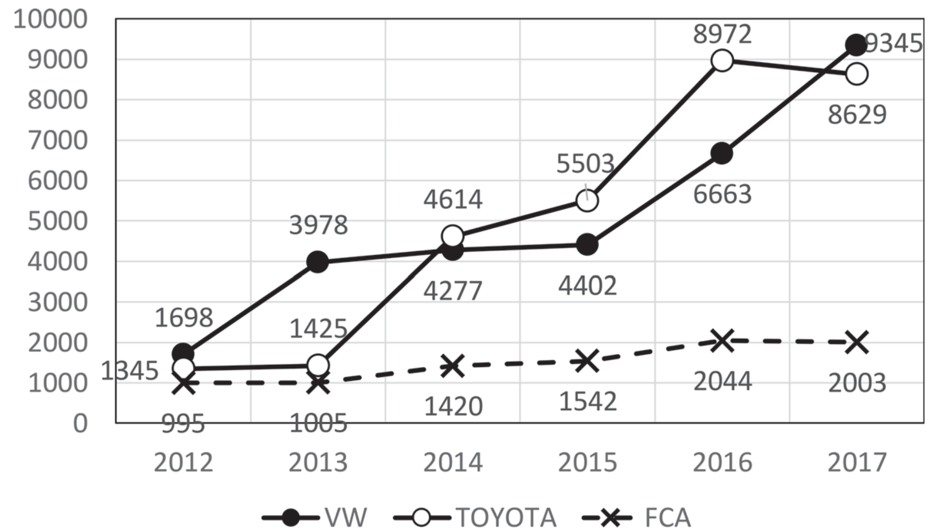

Figure 7.
Intensity of ECT (%) in the companies surveyed (source: author's own study).

stability of the time series with only periodic fluctuations is clearly visible. Toyota is a company with an established position in the market (which also applies to the entire Japanese economy); therefore, research and development expenditure is stable. Meanwhile, **Figure 5** clearly shows that the time series for investment in research and development in Toyota's cooperation with suppliers shows a clear upward trend. This means that the volume of this characteristic group of investments in research and development is systematically increasing. According to the Tapscott concept, this is a characteristic feature of all highly developed digital economies, which are called networks. In such economic systems, the level of investments in cooperative research and development increases significantly.

The following **Tables 2–5** show the correlation of operational variables for Toyota, VW, and FCA respectively, and the analysis of correlations from variables being the sum of data from the three surveyed companies.

The correlation analyses presented above reveal that in Toyota the variable (PIP) reflecting innovation performance and the variables (ER) and (ECT) achieved high correlation rates, which can be interpreted as follows: Toyota's innovation depends on cooperation with suppliers, and this cooperation largely depends on ITC systems connecting cooperating innovators.

Variables	(B + R)	(ER)	(EPS)	(ECT)	(NII)	(PIP)
(R&D)	0	—	—	—	—	—
(ER)	0.779	0	—	—	—	—
(EPS)	0.505	0.779	0	—	—	—
(ECT)	0.651	0.873	0.684	0		
(NII)	0.577	0.643	0.959	0.846	0	
(PIP)	0.430	0.630	0.899	0.866	0.974	0

Table 2.
Analyses of correlation of variables related to Toyota's R&D activity (source: author's own study).

Variables	(B + R)	(ER)	(EPS)	(ECT)	(NII)	(PIP)
(R&D)	0	—	—	—	—	—
(ER)	0.884	0	—	—	—	—
(EPS)	0.759	0.573	0	—	—	—
(ECT)	0.889	0.974	0.633	0		
(NII)	0.761	0.652	0.977	0.726	0	
(PIP)	0.879	0.767	0.777	0.843	0.834	0

Table 3.
Analyses of correlation of variables related to Volkswagen's R&D activity (source: author's own study).

Variables	(B + R)	(ER)	(EPS)	(ECT)	(NII)	(PIP)
(R&D)	0	—	—	—	—	—
(ER)	0.978	0	—	—	—	—
(EPS)	0.951	0.978	0	—	—	—
(ECT)	0.918	0.921	0.966	0		
(NII)	0.538	0.446	0.756	0.708	0	
(PIP)	0.740	0.724	0.849	0.812	0.807	0

Table 4.
Analyses of correlation of variables related to FCA's R&D activity (source: author's own study).

Variables	(B + R)	(ER)	(EPS)	(ECT)	(NII)	(PIP)
(R&D)	0	—	—	—	—	—
(ER)	0.948	0	—	—	—	—
(EPS)	0.818	0.948	0	—	—	—
(ECT)	0.987	0.980	0.768	0		
(NII)	0.794	0.637	0.995	0.748	0	
(PIP)	0.931	0.784	0.952	0.886	0.928	0

Table 5.
Analyses of correlation of variables related to R&D activity-sum of T, V, F (source: author's own study).

In addition, the above correlation analyses show that in Volkswagen the variable (PIP) reflecting innovation performance and the variables (R&D) and (ECT) achieved high correlation rates, which can be interpreted that VW's innovation depends primarily on its own R&D departments and expenditure on IT systems.

The above correlation analyses show that in FCA the variable (PIP) illustrating innovation performance and other variables obtained similarly high correlation rates. This means that FCA manages its innovation performance in a sustainable way.

Table 6 presents the analysis of correlations from variables being the sum of data from the three surveyed companies. A linear regression analysis was also carried out on the basis of aggregated data, which allows the simulation to be performed. It revealed that the following:

- An increase of 1% in expenditure on suppliers' development programmes (EPS) results in an increase in profits from the sale of innovative products (PIP) by 1.87% on average, as shown in **Figure 8**.
- The increase in ICT expenditure implemented to improve the efficiency of innovation processes with suppliers (ECT) by 1% results in an increase in profits from the sale of innovative products (PIP) by 0.18% on average, as shown in **Figure 9**.

Similar simulations will be the subject of further research, and decision-makers will be able to optimise expenditure on research and development activities implemented within the company and in cooperation.

Variable	Year							
	2010	2011	2012	2013	2014	2015	2016	2017
R&D*								
ER								
EPS								
ECT								
NII*								
PIP								

**http://iri.jrc.ec.europa.eu/scoreboard.html*

Table6.
Table for collecting data for correlation analysis in the "Model of innovation performance research of the supply chain leader".

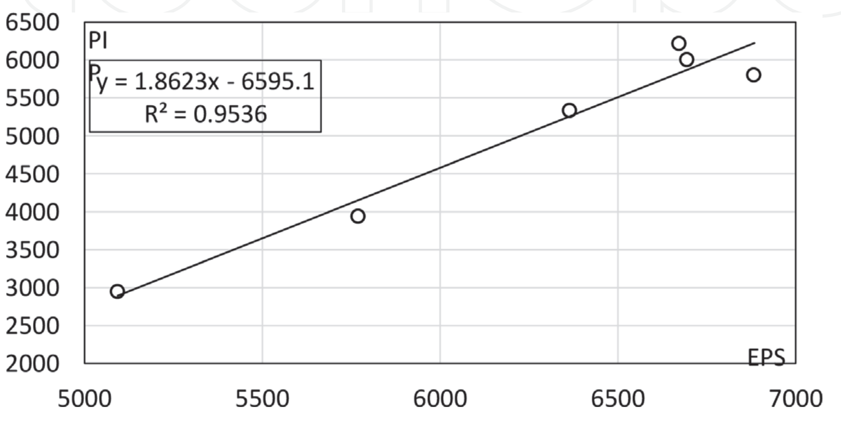

Figure 8.
Expenditure on suppliers' development programmes and profits from the sale of innovative products (source: author's own study).

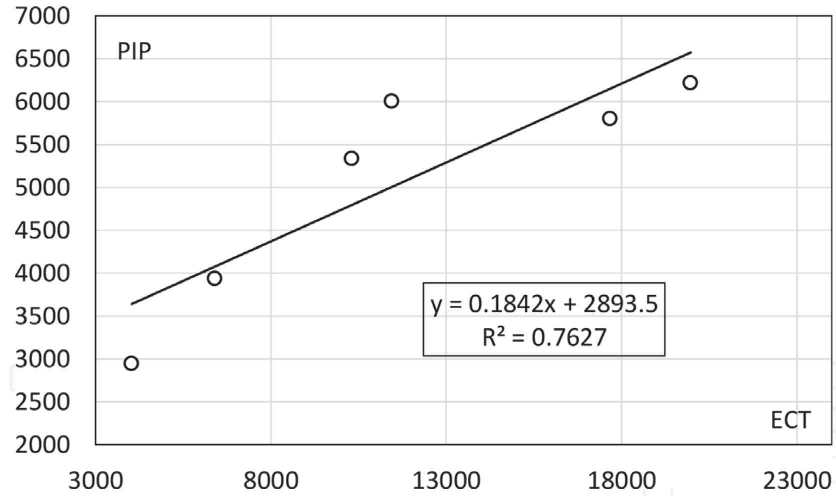

Figure 9.
Expenditure on ICT for OI and profits from the sale of innovative products (source: author's own study).

7. Discussion of the research results

Attempts to obtain quantitative data have shown that companies do not accumulate them in a way that would clearly identify expenditure on R&D in the open and closed model. Expenditure on suppliers' innovation development programmes is not measured. In addition, it was difficult for the companies to select expenditure on ITC (implemented for supporting research and development processes carried out in cooperation with suppliers). The analyses performed above further confirmed that the companies use simple indicators of their own and suppliers' innovation performance (although researchers are already offering more advanced assessment methods).

The researcher notices a number of limitations for the conducted research, affecting the reliability of the presented analyses. All correlation analyses should be based on reliable, publicly available financial documents. The correlation indicators presented in the paper may, however, contain errors, as their calculations are based on estimated data. The estimated data were received from the automotive companies' central offices (through responders-response portals of surveyed companies, using the questionnaire—**Annex 1**) as a percentage of the values reported in official documents. It was argued that corporations do not keep records of expenditure in the layout desired by the created research model. The implementation of the suppliers' innovation management model means defining and monitoring indicators that make it possible to measure expenditure on research and development in the open model in the future.

8. Conclusions

Estimated analyses clearly show that the increase in expenditure on research and development activities in the open innovation model translates into an increase in the innovation performance of the supply chain integrator. It was shown that optimising expenditure on research and development activities (i.e., gradual abandonment of expenditure on internal R&D activities and an increase in expenditure on the development of suppliers' innovation) results in a significant increase in the innovation performance of automotive companies.

It was considered right to prepare a digital model for suppliers' innovation management that would be implemented in an automotive company. Its primary goal would be to optimise expenditures on research and development activities carried out together with suppliers. While preparing the model, the leading role of the company in the supply chain and its irreplaceable influence on improvements to suppliers' innovation were recognised. It seems that the surveyed companies still have an indifferent attitude towards new ICT technologies used to develop innovations in the open model. They invest little in modern ICT systems and do not measure the effectiveness of these expenditures.

Summarising the attempt to implement a digital model of suppliers' innovation management, it should be noted that an analytical look at the R&D field is not possible right now due to the lack of properly collected data. The proposed model of suppliers' innovation management could be implemented in the IT system of the automotive company and serve as a tool supporting the development of innovation in the open model. The idea of implementation was discussed with a specialist-an employee of the SAP company (who is responsible for cooperation with companies from the automotive industry). The idea was found to be of interest and confirmed feasible.

The presented research will further deepen the discussion on digital innovation management of suppliers in the supply chain.

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Conflicts of interest

The author declares no conflict of interest.

A. Annex 1

A.1 Suppliers' innovation management

Dear Sir or Madam. Correlation of variables from this table is the culmination of my research work. I would like to show that including suppliers in the process of developing innovative products influences the profits of automotive companies. I am asking you for approximate percentages only. Thank you in advance for these data/variables:

R&D Expenditure on R&D.

ER R&D expenditure realised jointly with suppliers *in EUR million* (estimated by the respondent as a percentage of expenditure on R&D).

EPS Expenditure on suppliers' innovation development programmes in EUR millions (estimated value by the respondent, companies do not distinguish these costs).

ECT Expenditure on ICT to improve the processes of innovation development with suppliers in EUR millions (estimated by the respondent as a percentage of expenditure on CapEx).

NII Expenditure on R&D per year/net sales per year-Intensive R&D).

PIP Profits generated on innovative products (as a percentage of operating profit).

Glossary of used terms and abbreviations

R&D	(Research and Development); usually team activities of scientific or technical nature. Activities can be divided into basic, applied, and developmental research.
OI	(Open Innovation)-A concept popularised by the professor and executive director of the Open Innovation Center at the University of Berkeley, Henry Chesbrough. According to this concept, enterprises should not rely solely on the results of their own research and development work but use external sources of innovation through cooperation with other entities.
ICT	(Information and Communication Technologies)-Information and communication technologies. The concept includes technologies that process, collect, and send information in electronic form.
NDA	(Non-Disclosure Agreement)-a contract of confidentiality that obliges its parties to exchange confidential materials or information subject to their further non-dissemination. The NDA is also known as the CDA (confidential disclosure agreement).
CDM	(acronym of the three authors' names) or Mairesse Model-an econometric analysis used at the company level to study innovation and productivity, introducing concepts and definitions: IP-Innovation Performance/Innovation.
IP	Innovation Performance/Innovation. The assessment of IP consists of: profits from the sale of innovative products, the number of implementations of innovative solutions, the quality of implemented innovative solutions, effectiveness and efficiency of product development processes.

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