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VERIFICATION OF THE PRODUCTION STRUCTURE EVOLUTION MODEL OF INDUSTRIAL ENTERPRISES USING CLUSTER ANALYSIS

Abstract:

The article is focused on identifying patterns of organizational development of industrial enterprises on the example of the Czech Republic and verifying the applicability of the developed theoretical model of the evolution of the production (operational) structure of organizations in the real sector of the economy. The proposed production (operational) structure evolution model (PSEM) is based on the hypothesis about the existence of two basic types of production (operational) structures – sequential and parallel. In the process of growth and development of organizations, these structures dialectically replace each other, moving to a qualitatively new level of development. Within the framework of this article, the objects of the study are enterprises of the metallurgical industry (NACE codes 24.1, 24.2, 24.4 and 24.5) located on the territory of the Czech Republic. Cluster analysis was used as the main research method. The results of the study generally confirmed the hypothesis put forward about two basic types of organizational production (operational) structures and the theoretical model of PSEM. A comparative analysis was also carried out with the previously obtained results of a study to verify the model of the evolution of the production (operational) structure of enterprises producing equipment for vehicles of the Czech Republic. The comparative analysis has shown that, firstly, the proposed theoretical model of PSEM for the selected industries is the same. Secondly, a comparison of the set of indicators used in the model of PSEM of organizations in the real sector of the economy for two different industries showed their significant coincidence.

Keywords:

Industrial enterprises, Metallurgical industry, Organizational development, Cluster analysis

JEL Classification: C10, C38, C52

1 Introduction

The peculiarity of the functioning of metallurgical industry enterprises implies that such companies are heavily built into the production value chains of various types of final products: mechanical engineering, automotive industry, shipbuilding, etc. Thus, the development and growth of metallurgical industry enterprises, generally, involves the expansion of activities within the value chain they are embedded in, or the extension of their embeddedness into other value chains, i.e. building integrated structures. In turn, the establishment of integrated structures is possible either within the framework of vertical or horizontal integration.

Based on the research findings on the production structures of industrial companies (Burns, Stalker, 2011; Wildemann, 1992), as well as considering the aforementioned features of the metallurgical industry, a typology of industrial companies has to reflect two basic types of production structures – sequential and parallel. Within the framework of the ongoing research, a sequential structure is defined as a company (or a company group) structure in which, if any of the elements (or one of the entities) ceases to operate, the production process is completely disrupted. Accordingly, a parallel structure is understood as a company structure in which, if any of the elements (or one of the entities) ceases to operate, the production process will not be disrupted but lead to reduction of production volumes.

Based on the proposed typology of production (operational) structures, a hypothesis was put forward that the two basic types of structures – sequential and parallel, replace each other in the process of growth of production organizations. This approach is based on the dialectics of the development process, according to which sequential production structures are transformed into parallel ones as the organization grows, and then, at a new stage of development, parallel structures are transformed into sequential ones. The proposed approach was previously tested in relation to other economy sectors of the Czech Republic (Bobkov, Denisov, Kuchmaeva, 2017, 2019; Bobkov, Denisov, 2017; Bobkov, Denisov, Tsenina, Velinov, 2019; Bobkov, Denisov, Tsenina, 2018; Bobkov, Denisov, Kuchmaeva, Savchina, 2019; Bobkov, Denisov, Kuchmaeva, Savchina, 2020) and the results generally confirmed the hypothesis put forward. Within the framework of this study, the metallurgical companies of the Czech Republic (NACE codes 24.1, 24.2, 24.4 and 24.5) were selected as an object of study. The choice of the research object was determined by the following factors:

- association to the industrial production sector;

- the companies selected for the study have similar approaches to the organization of production processes and, consequently, to the formation of the production structure;
- the number of companies selected for the study and the list of indicators of their financial and economic activities should ensure that the results of the study are correct.

Prior to the study, the metallurgical companies were selected based on their direct involvement in the production of metallurgy products or in their primary processing. The selection was made on the basis of economic activities (NACE codes) specified in the database.

2 Research methodology

Numerous researchers have previously conducted research to identify patterns of organizational development using quantitative indicators (Hanks, Watson, Jansen, Chandler, 1993; Shirokova, 2009). The methodology for conducting these studies did not differ much among researchers and included the following steps:

- Data collection about the companies under study, including the values of indicators of their financial and economic activities;
- Preliminary processing of the data received and selection of variables characterizing the organizational structure;
- Cluster analysis using the Ward's method for selected variables;
- Evaluation of the results of cluster analysis by clusters;
- Interpretation of the results of cluster analysis.

When interpreting the results of cluster analysis in the above studies, an attempt was made to empirically determine the levels of development of the organizations under study in accordance with the assignment to the corresponding cluster and, then, based on the results obtained, develop a model of organizational development. However, in the opinion of the researchers themselves, the results obtained did not allow them to come to definite conclusions about the sequence of stages in the development of organizations assigned to different clusters (Hanks, Watson, Jansen, Chandler, 1993; Shirokova, 2009).

The lack of positive results in previous studies, according to the authors, could be due to several factors:

1. Initial information was obtained by surveying the managers of the studied companies. Accordingly, the qualitative variables chosen by the

researchers to identify the patterns of organizational development could be interpreted by the respondents in completely different ways.
2. The number of organizations in the samples was relatively small and did not exceed 160 companies in different studies. Taking into account the fact that the sample included companies from various sectors of the economy, this only increased the sectoral differences.
3. When conducting cluster analysis, only structural variables were mainly used. Variables characterizing the results of financial and economic activities were used either only to interpret the results obtained or were not used at all.

In contrast to previous studies, in this study, a model for the development of the production structure of industrial enterprises was previously developed in accordance with the hypothesis put forward. After that, the developed model was verified. The research methodology included the following steps:

1. Extracting information about the companies under study from the Albertina Gold Edition and Amadeus databases;
2. Integration of the information received about the companies under study into a single database;
3. Selection of two groups of variables: variables characterizing the structure of companies and variables characterizing the results of their financial and economic activities using the Pearson correlation matrix of paired coefficients of mutual contingency;
4. Carrying out the Ward's method of cluster analysis for the selected variables;
5. Analysis of the results of cluster analysis in the context of clusters;
6. Comparison of the obtained results with the proposed theoretical model for the development of the organizational structure of industrial companies.

To confirm the production structure evolution model (PSEM), cluster analysis was used, carried out using the IBM SPSS program. Raw data was obtained from the Albertina Gold Edition and Amadeus databases. 364 metallurgical companies (NACE codes 24.1, 24.2, 24.4 and 24.5) of the Czech Republic were selected for the study based on the results of their economic activities for the 2019 calendar year (from 01/01/2019 to 12/31/2019). The choice of the year was due to the completeness of the information. Financial indicators were calculated in the original currency – Czech crowns (CZK).

3 Research results

The PSEM of organizations implies that the growth of organizations and the improvement of their production (operational) activities is possible up to a certain limit, associated with existing technological limitations and causing a limit to further productivity growth. Such a hypothesis is based both on the sustainable growth model of enterprises (Van Horne, Wachowicz, 2008) and on the life cycle model (Hanks, Watson, Jansen, Chandler,1993). In order to ensure the further growth of the organization, when the growth limit is reached, the company management needs to carry out its structural transformation. Such transformations can be done in one of two ways. If an organization consists of one enterprise or uses a vertical integration of the production process (i.e. has a sequential structure in the terminology adopted in this study), duplication of the main activity occurs with the allocation of separate legal entities, including those built into other value chains (i.e. moves to a parallel structure). If the organization is already using a parallel structure (i.e. the organization is a network or horizontally integrated structure), then further development is carried out by extending the value chain within one larger structure, i.e. a vertically integrated structure is being formed.

The organizational characteristics of each level of development of industrial organizations within the framework of the PSEM of industrial enterprises is presented in Table 1.

Table 1. Production structure evolution model of real economy sector companies

Level of development	Type of industrial enterprise	Type of production structure
1	small production company	sequential
2	network of small production companies	parallel
3	industrial company	sequential
4	network of industrial companies	parallel
5	large company / vertically integrated company	sequential
6	horizontally integrated company	parallel

Source: developed by the authors

To confirm the hypothesis put forward and the PSEM concept in the real economy sector, a study was conducted according to the aforementioned method.

In accordance with the research methodology, two groups of variables were selected: variables characterizing the structure of the organization (the first group of variables), variables characterizing the results of financial and economic activities of organizations (the second group of variables). To identify the second group of variables using the IBM SPSS program, a matrix of paired Pearson's mutual contingency coefficients was constructed based on the condition for ensuring significant correlation with structural variables. The calculation of the matrix of pairwise Pearson correlation coefficients is presented in Table 2.

Table 2. Pearson's matrix of pairwise conjugacy coefficients

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1	0.396*	0.017	0.082	0.383*	0.395*	0.406*
X_2	0.396*	1	0.668*	0.710*	0.966*	0.999*	0.980*
X_3	0.017	0.668*	1	0.877*	0.590*	0.656*	0.594*
X_4	0.082	0.710*	0.877*	1	0.711*	0.710*	0.649*
X_5	0.383*	0.966*	0.590*	0.711*	1	0.971*	0.963*
X_6	0.395*	0.999*	0.656*	0.710*	0.971*	1	0.982*
X_7	0.406*	0.980*	0.594*	0.649*	0.963*	0.982*	1

** The correlation is significant at the 0.01 level (2-sided).*
Source: developed by the authors

The selected variables of the first and second groups are presented in Table 3.

Table 3. Variable notation and list of indicators used in the cluster analysis

First group of variables		Second group of variables	
Variable notation	Indicator name	Variable notation	Indicator name
X_1	Number of legal entities (units)	X_4	Total assets value (thousand CZK)
X_2	Average number of employees (people)	X_5	Total revenue per company (thousand CZK)
X_3	Average number of employees per company (people)	X_6	Labor costs (thousand CZK)
-	-	X_7	Value added

			(thousand CZK per month)

Source: developed by the authors

For the selected variables, a cluster analysis was carried out using the Ward's method, which makes it possible to divide the set into a sufficient number of clusters corresponding to the economic essence of the phenomena under study. The cluster analysis was carried out on a sample of 363 metallurgical companies in the Czech Republic.

The hypothesis of equality of variances within and between clusters is rejected for all variables at 3 and 359 degrees of freedom. The p-value is the probability of error when accepting the hypothesis of inequality of variances, no more than 0.01 (F-criterion is significant for all variables at a level of at least 0.01). This suggests that the hypothesis of inequality of variances is accepted and, accordingly, the clusters are formed correctly.

The result of the cluster analysis was the division of 363 companies into 4 clusters (see Table 4). Clusters are sorted by the growth of the average value of the variable "total assets value", since previous studies have revealed the dependence of changes in structural variables with an increase in the value of the organization's total assets value (Bobkov, Denisov, 2017; Bobkov, Denisov, Kuchmaeva, Tsenina, Velinov, 2019; Bobkov, Denisov, Tsenina, 2018). As an additional structural variable used to interpret the results of cluster analysis, we used the variable X_8 – the number of subsidiaries.

Table 4. Average values of variables in clusters, sorted by the total assets value

Variable notation	Indicator title	Cluster 1 N=328	Cluster 4 N=32	Cluster 3 N=1	Cluster 2 N=2
X_1	Number of legal entities (units)	1.6	2.1	1.0	7.5
X_2	Average number of employees (people)	106	632	1,192	7,500
X_3	Average number of employees per company (people)	75	390	1,192	1,102
X_4	Total assets value (thousand CZK)	174.7	1,710.0	8,267.3	30,370.5
X_5	Total revenue per company	171.1	1,628.4	5,087.0	6,415.2

	(thousand CZK)				
X_6	Labor costs (thousand CZK)	45.8	262.3	533.7	3,261.0
X_7	Value added (thousand CZK per month)	69.1	494.1	787.7	6,204.0
X_8	Number of subsidiaries (units)	0.2	1.0	0	15.0

Source: developed by the authors

Evaluating the obtained results of distribution by clusters after sorting by the value of total assets (X_4) (see Table 4), a consistent increase and decrease in the values of the variables Number of legal entities (X_1) and Number of subsidiaries (X_8) is observed.

Analyzing the average values of variables in clusters, it can be seen that cluster 1 is predominantly represented by individual enterprises (the average value of the number of legal entities is 1.6 (X_1) and, on average, 1 subsidiary per 5 companies analyzed). That is, cluster 1 contains companies that have a predominantly sequential structure.

Cluster 4 contains companies that have a predominantly parallel structure. Each organization in this cluster, on average, has a little more than two separate legal entities (X_1=2.1) and one subsidiary.

In cluster 3, there is a decrease in the average number of entities and there are no subsidiaries, which indicates the structural transformation of the organization of this cluster to a sequential structure.

In cluster 2, there is again a significant increase in both the average number of legal entities (X_1=7.5) and the average number of subsidiaries (X_8=15.0), which can be interpreted as a structural transformation of organizations in this cluster to parallel structures.

It is also necessary to note another interesting pattern: the transition to sequential structures is accompanied by a higher growth rate of relative indicators. In particular, the growth in revenue attributable to one legal entity.

Table 5 compares the results of the cluster analysis of metallurgical industry companies with the proposed PSEM of organizations in the real economy sector.

Table 5. Comparison of the results of the analysis of the development patterns of metallurgical enterprises with the production structure evolution model of companies in the real economy sector

Cluster number	Number of companies	Company type	Production structure type
1	328	industrial company	sequential
4	32	network of industrial companies	parallel
3	1	large vertically integrated company	sequential
2	2	large horizontally integrated company	parallel

Source: developed by the authors

If we compare the results obtained with the results of previously conducted studies for organizations in the real sector of the economy (Bobkov, Denisov, Kuchmaeva, Tsenina, Velinov, 2019; Bobkov, Varyan, 2020) then:

1. In all the conducted studies, the proposed theoretical model of the development of the production (operational) structure of organizations in the real sector of the economy was confirmed;
2. For metallurgical enterprises and enterprises producing equipment for motor vehicles, the model of development of the production (operational) structure is the same (see Table 6). Such a coincidence may indicate similar patterns of development of enterprises that ensure the production of final products.

Table 6. Comparison of the results of the analysis of the patterns of development of enterprises for the production of equipment for motor vehicles with the theoretical model of the development of the production (operational) structure of organizations in the real sector of the economy

Cluster number	Number of companies	Company type	Production structure type
1	188	industrial company	sequential
2			
3	31	network of industrial companies	parallel
4			

5	1	large vertically integrated company	sequential
6	2	large horizontally integrated company	parallel

Source: Bobkov, Varyan, 2020

Further comparative analysis of the comparison of a set of indicators that were identified during the verification of the theoretical model of the development of the production (operational) structure of organizations in the real sector of the economy showed their significant coincidence (see Table 7).

Table 7. Comparison of a set of variables obtained from the results of cluster analysis when verifying the theoretical model of the development of the production (operational) structure of organizations in the real sector of the economy for two sectors of the economy

	Production of the equipment for motor vehicles	Metallurgical industry
	Structural variables	
1	Number of legal entities (units)	Number of legal entities (units)
2	Average number of employees (people)	Average number of employees (people)
3	Average number of employees per company (people)	Average number of employees per company (people)
	Variables characterizing the results of financial and economic activities	
4	Total assets value (thousand CZK)	Total assets value (thousand CZK)
5	Value added (thousand CZK/month)	Value added (thousand CZK/month)
6	Labor costs (thousand CZK)	Labor costs (thousand CZK)
7	Total revenue (thousand CZK)	Total revenue per company (thousand CZK)
8	Cost of production (thousand CZK)	-

Source: developed by the authors

4 Discussion

Similar studies were previously carried out by the authors in other real economy sectors. In particular, for the companies of the automotive industry of the Czech Republic (Bobkov, Denisov, Kuchmaeva, Tsenina, Velinov, 2019; Bobkov, Denisov, Kuchmaeva, Savchina, 2020; Bobkov, Varyan, 2020). At the same time, considering the results of verification of the PSEM of companies producing equipment for motor vehicles in the Czech Republic, out of the seven or eight variables used in the cluster analysis, six variables are identical for companies in two different sectors of the economy (see Table 7). This may indicate the universal nature of both the proposed PSEM of organizations in the real sector of the economy, and the factors that

determine the development of industrial enterprises. However, to confirm this hypothesis, it is necessary to conduct more detailed studies, including the expansion of the list of studied economy sectors.

5 Conclusion

Based on the results of the study, the following conclusions can be drawn:

1. The results of the study of metallurgical industry companies of the Czech Republic confirmed the hypothesis put forward about the presence of patterns in the development of the production (operational) structure of organizations in the real economy sector and made it possible to verify the proposed production structure evolution model (PSEM) of such organizations.

2. A set of indicators was identified that determine the transformation of changes in the production (operational) structure of enterprises in the metallurgical industry.

3. The use of an additional indicator, the number of subsidiaries (X_8) for interpreting the results of cluster analysis, confirmed the correctness of attributing enterprises to the corresponding clusters.

4. Comparison of a set of indicators that determine the transformation of changes in the production (operational) structure of enterprises in various industries showed their partial coincidence.

5. Using the production structure evolution model (PSEM) of organizations in the real economy sector increases the effectiveness of development strategies.

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