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ISMSME International Society for Manufacturing, Service and Management Engineering

received: 15 January 2020
accepted: 15 June 2020

pages: 7-20

Optimisation of the relationship between structural parameters of the processing industry as a way to increase its efficiency

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ABSTRACT
Industry, which on average accounts for about 60% of commodity exports in the EU-28, with over 58% resulting from the processing industry, plays a key role in ensuring the competitiveness of EU countries. The article aims to simulate the influence of structural processing industry parameters on the industry's efficiency. Correlation methods and the regression analysis were used to substantiate the hypotheses regarding the effect that the share comprised of high-tech and medium-high-tech industries has on the output structure, and the impact made by the share of imports in the intermediate consumption of those industries on the efficiency (the share of gross value added (GVA) in output) of the processing industry. Based on the criteria indicating the increased technological level and reduced import dependence, economic and mathematical models of optimisation were created for the output structure and intermediate consumption of the processing industry, which were then solved using the linear programming method. The authors present the mathematical proof of the relationship between the change in structural parameters (shares of high-tech and medium-tech industries and the share of imports in the structure of their intermediate consumption) of the processing industry and the ratio of the gross value added/output. The results of the simulation, which were based on data from the European Statistical Office and the Organization for Economic Cooperation and Development, provide an analytical basis for selecting industrial policy benchmarks.

KEY WORDS
processing industry structure, efficiency, gross value added, share of output, share of imports, intermediate consumption, optimisation

10.2478/emj-2020-0008

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Introduction

The deepening globalisation has had a generally positive impact on economic development, and in particular, foreign trade; however, it also intensified competition in the world market. Under such conditions, the industrial sector plays a key role in ensuring the competitiveness of EU countries, as it accounts for about 60% of commodity exports on average in the EU-28, with over 58% resulting from the processing industry. The processing industry is the manufac-

Citation: Ishchuk, S., Sozanskyy, L., & Pukała, R. (2020). Optimization of relationship between structural parameters of processing industry as a factor influencing its effectiveness. *Engineering Management in Production and Services, 12*(2), 7-20. doi: 10.2478/emj-2020-0008

turing sector, in which enterprises use physical or chemical processes to transform materials, substances or components into new products. According to the European Classification of Economic Activities NACE Rev.2, processing covers 33 industries, which can be classed into the following groups: food, woodworking, textile, chemical, oil refining, metallurgy, engineering, furniture, repair, and installation of machinery and equipment.

Since industrial enterprises produce about 50% of intermediate consumption products, their results determine the external trade balance of EU countries as well as the state of their economy in general. Industry — and primarily its processing sector — remains the leading economic activity, which can be evidenced by intensified reshoring processes in developed EU countries. However, a high level of efficiency must be achieved to maintain competitiveness or the enduring ability to withstand competition with the help of the available potential. This largely depends on the existing structural parameters, by which this study understands the relationship between the shares of different types of industry (based on the level of manufacturability — high-tech, medium-high-tech, moderately-low-tech and low-tech) in output of the processing industry.

This article is a logical continuation and further extension of research results aspiring to actualise the problematic issues arising from the functioning of the industrial sector of the economy, particularly aimed at finding and justifying ways for increasing the efficiency of the processing industry in EU countries and creating appropriate optimisation models.

The article intends to simulate the influence made by structural parameters of the processing industry on the industry's efficiency. This problem statement follows from previous studies made by the authors of this article. As hypothesised by Ishchuk (2018) and Sozanskyy (2018a, 2018b), the relationship between the structural parameters of the processing industry significantly affects the efficiency (namely, share of GVA in output). This hypothesis was confirmed by the results of research conducted in the Ukrainian processing industry. Based on this hypothesis, the authors used their original economic and mathematical model (Ishchuk, 2018; Sozanskyy, 2018b) to optimise the structure of the Ukrainian industrial production to the level of Poland using the criteria for increasing efficiency and manufacturability.

However, the question arises regarding the relevance of the hypothesis, the applied methodological approach and the developed economic and mathematical model for other countries, especially in the EU, which differ in terms of economic scale and specialisation of the processing industry. This study is also relevant because of the issue of structural transformations in the economy in general and the industrial sector in particular, as well as the expediency to use optimisation models, which has been the subject of many other studies.

For example, Wlodarczyk (2013) presented an overview of structural changes in the Polish food industry over the period 2000–2012 and the optimisation of the structure of production factors using nonlinear programming methods. The optimisation of the sectoral structure of economic resources to maximise Turkey's income using linear programming methods was described in detail by Can (2012) and Atlan (2016). Čapek (2016) used the dynamic stochastic general equilibrium (DSGE) model and Bayesian methods to present an estimation of structural changes in the Czech economy over the period 1996–2002. Taušer (2015) used the autoregressive distributed lag (ADL) model to demonstrate a high correlation between the Czech exports and the German GDP as well as the significant integration of the Czech and German economies. Olczyk (2017) applied the sectorial approach and the error correction model to assess the international competitiveness of the Czech industry. This facilitated conclusions regarding the significant dependence of Czech exports on imported components.

Vogstad (2009) offered a broad overview of the possibilities and examples to apply linear programming methods as well as input-output data tables in resource optimisation processes. Tan et al. (2019) presented models for optimising interconnections between industry sectors to improve export and import tactics. And Sharify (2018) discussed the theoretical and methodological principles for the application of the nonlinear supply-driven input-output model.

However, the available studies paid insufficient attention to modelling the impact made by structural parameters of the processing industry on the industry's efficiency, and especially to the comparison of different countries. Research on this topic rarely includes a comprehensive scientific approach that covers the entire spectrum from problem argumentation and the proposal as well as confirmation of hypotheses to their justification and testing by models, formulation of scientific and analytical conclusions and recommendations that could be potentially

applied in the realm of the real economy. Also, researchers rarely use the information capabilities of input-output tables, specifically in the assessment of the degree of import dependence particular to economic sectors.

1. Research method

The authors of the article used the results of thorough analytical studies into the industrial sector of the economy of three selected countries (Poland, Germany and the Czech Republic) to hypothesise that a higher share of high-tech and medium-high-tech industries in the structure of processing industry's output results in a higher share of GVA in output for this type of industrial activity. However, this hypothesis was fully empirically confirmed only for Poland and Germany as the results of correlation-regression analysis established the existence of a stochastic and linear relationship, which was very close to deterministic, and a direct relationship between changes in the studied parameters. This hypothesis was not fully confirmed for the Czech processing industry due to a relatively low closeness of the relationship between the change in the selected parameters. These conclusions resulted in further detailed studies of the Czech processing industry, which served as the basis for the second hypothesis, stating that a lower share of imports in the intermediate consumption of high-tech and medium-high-tech industries results in a higher share of GVA in the processing industry's output. This hypothesis was empirically confirmed by the results of the correlation-regression analysis, which showed the presence of a close stochastic relationship and the inverse relationship between changes in the studied parameters.

The formulated and confirmed hypotheses became the methodological basis for optimising the structure of the processing industry in Poland and the Czech Republic according to the criteria of an increasing level of manufacturability and reducing import dependence. The target function of the optimisation was the efficiency index of the German processing industry, which is the industry leader in the EU. Determinative multiplicative models were used for optimisation because of a functional relationship between the share of GVA in output and the selected structural parameters. Actual data (structural indicators of the industry of the studied countries) was used to test the mathematical adequacy of the models. As linear programming methods allow the most accurate solutions for optimisation tasks, they were used to solve the models. As discussed in the literature overview, these arguments have been confirmed by modelling results of the economic processes of different countries.

Data for analytical assessments were sourced from the European Statistical Office (2016, 2019), the United Nations Industrial Development Organization (2019) and the Organization for Economic Cooperation and Development (OECD), including input-output tables and national accounts. The methodological basis of the research included general scientific, economic-logical and economic-mathematical methods of economic analysis, in particular such methods as cognition theory, deterministic factor and general analysis, correlation-regression analysis, and linear programming.

The following text presents the algorithm for solving the tasks, as well as the most important results of the authors' in-depth analytical research on the formation and confirmation of hypotheses, the elaboration and solution of optimisation models.

Having similar industrial potential parameters, Poland and Germany are among the most industrialised countries of the EU. In 2017, Poland exceeded Germany by 9.18 percentage points (pp) (45.53% vs 36.35%) in terms of the level of industrialisation (the share contributed by industry to gross domestic product (GDP)); whereas in 2014, Poland was in the lead only by 1.1 pp (37.74% vs 36.64%). In absolute numbers of output and GVA, the Polish industry was inferior to the German in 2017, respectively by 6.41 and 5.80 times, while in 2014, the differences between the values amounted to 6.64 and 7.26 times. At the same time, by share of GVA in output (which is one of the main indicators of the economic efficiency), the German industry has had a constant advantage (≈4 pp) over the Polish industry with 34.57 % vs 30.49% in 2017 (33.69% vs 29.90% in 2014).

One of the main reasons for such differences is the relatively lower efficiency of the Polish processing industry. Thus, by share of GVA in the processing industry's output in 2017, Poland was inferior to Germany by 7.05 pp. The German processing industry exceeded the Polish in all high-tech and medium-high-tech industries without exception, and so it did in 2017, in the vast majority of other industries, based on this indicator of efficiency (Table 1). The Polish processing industry had insignificant advantages in two low-tech (manufacture of textiles, wearing apparel, leather and related products; and manufacture of wood, paper, printing and reproduction) and

Tab. 1. Share of gross value added in the processing industry's output in 2017 (%)

The group	The manufacturing	Classification code of economic activities NACE Rev. 2	Poland	Germany
The high-tech	Manufacture of basic pharmaceutical products and pharmaceuticals	C21	32.40	53.64
	Manufacture of computers, electronic and optical products	C26	17.51	45.96
The medium-high-tech	Manufacture of chemicals and chemical products	C20	26.17	32.90
	Manufacture of electrical equipment	C27	22.08	41.01
	Manufacture of machinery and equipment not elsewhere classified	C28	32.30	37.94
	Manufacture of motor vehicles, trailers and semi-trailers	C29	20.26	33.41
	Manufacture of other transport equipment	C30	31.42	32.70
The moderately-low-tech	Manufacture of coke and refined petroleum products	C19	16.03	10.37
	Manufacture of rubber and plastic products	C22	28.84	35.19
	Manufacture of other non-metallic mineral products	C23	34.90	36.77
	Manufacture of basic metals	C24	17.77	19.96
	Manufacture of fabricated metal products, except machinery and equipment	C25	34.99	41.15
	Repair and installation of machinery and equipment	C33	48.11	36.06
The low-tech	Manufacture of food products; beverages and tobacco products	C10-12	23.67	23.75
	Manufacture of textiles, wearing apparel, leather and related products	C13-15	35.62	32.88
	Manufacture of wood, paper, printing and reproduction	C16-18	30.91	30.07
	Manufacture of furniture; other manufacturing	C31-32	32.66	45.09
Total processing industry			**27.01**	**34.06**

Source: elaborated by the authors based on Eurostat data (Eurostat, 2016).

two medium-low-tech industries (manufacture of coke and refined petroleum products; and repair and installation of machinery and equipment).

Hence it follows, that a higher economic efficiency of the German processing industry (as compared to the Polish) can be explained by its greater orientation towards high-tech industries and industries with a higher degree of raw material processing. This thesis was confirmed by the comparison of GVA and output structures of processing industries in these two countries (Table 2).

Thus, the share of high-tech and medium-high-tech industries in the output structure of the German processing industry is 1.8 times larger than in Poland. The German processing industry is founded on medium-high-tech industries that comprise 51.04%, of which 21.14% is the production of motor vehicles, trailers and semitrailers. Meanwhile, the Polish processing industry is supported on low-tech industries that amount to 35.21%, of which 19.89% is the manufacture of food products, drinks and tobacco products.

In the case of Poland and Germany, a close relationship exists between the dynamics particular to the share of high-tech and medium-high-tech industries in the structure of the processing industry's output on the one hand, and the share of GVA in the processing industry's output on the other. During the studied period, both Poland and Germany saw the increase in the share of medium-high-tech industries in the structure of the processing industry's output, which concurred with the increase in the share of GVA in the processing industry's output (Figs. 1 and 2). The exception was the post-crisis year 2010 in Poland.

The correlation and regression analysis established a stochastic and linear correlation, which was very close to functional (deterministic), since the correlation coefficients between the studied indicators for Poland and Germany were very high, respectively, 0.91 and 0.92 (Figs. 3 and 4). The values for the coefficient of determination (R) show that in the analysed period, share of GVA in the Polish and German processing industry's output depended on the share (total) of high-tech and medium-high-tech industries in the structure of the processing industry's output by 83.20% and 84.64%, respectively.

Thus, an analytical review and results of the correlation and regression analysis of Poland and Germany confirmed the hypothesis stating that a higher share of high-tech and medium-high-tech industries in the structure of the processing industry's output

Tab. 2. Structures of gross value added and output of the processing industries in Poland and Germany in 2017 (%)

The group	The manufacturing	Classification code of economic activities NACE Rev.2	The structure of gross value added		The output structure	
			Poland	Germany	Poland	Germany
The high-tech	Manufacture of basic pharmaceutical products and pharmaceuticals	C21	1.58	3.33	1.32	2.12
	Manufacture of computers, electronic and optical products	C26	2.09	6.08	3.22	4.50
	Total		**3.67**	**9.41**	**4.54**	**6.62**
The medium-high-tech	Manufacture of chemicals and chemical products	C20	4.93	7.47	5.09	7.73
	Production of electric equipment	C27	3.69	6.72	4.52	5.58
	Manufacture of machinery and equipment not elsewhere classified	C28	4.64	15.41	3.88	13.84
	Production of motor vehicles, trailers and semitrailers	C29	8.77	20.74	11.69	21.14
	Manufacture of other transport equipment	C30	2.08	2.64	1.79	2.75
	Total		**24.11**	**52.98**	**26.96**	**51.04**
The moderately-low-tech	Production of coke and coke products of oil refining	C19	3.16	0.82	5.32	2.71
	Manufacture of rubber and plastic products	C22	7.76	4.47	7.27	4.32
	Manufacture of other non-metallic mineral products	C23	5.70	2.65	4.41	2.46
	Metallurgical production	C24	2.82	3.09	4.29	5.27
	Manufacture of fabricated metal products, except machinery and equipment	C25	11.56	8.45	8.92	6.99
	Repair and installation of machinery and equipment	C33	5.48	2.30	3.07	2.18
	Total		**36.48**	**21.78**	**33.29**	**23.93**
The low-tech	Manufacture of food products; beverages and tobacco products	C10-12	17.43	6.93	19.89	9.94
	Manufacture of textiles, wearing apparel, leather and related products	C13-15	3.42	1.15	2.59	1.19
	Manufacture of wood, paper, printing and reproduction	C16-18	8.94	3.79	7.81	4.29
	Manufacture of furniture; other manufacturing	C31-32	5.95	3.96	4.92	2.99
	Total		**35.73**	**15.83**	**35.21**	**18.41**
Total processing industry			**100.00**	**100.00**	**100.00**	**100.00**

Source: elaborated by the authors based on Eurostat data.

results in a higher share of GVA in output generated by this type of industrial activity. It follows that the optimisation of the processing industry structure (in terms of particular industries) is a way to increase the industry's efficiency.

The authors developed an economic and mathematical model to optimise the structure of processing industry's output using the criterion for increasing efficiency (i.e., achieving the desired share of GVA in output). The optimisation model (1) is deterministic and reflects a functional relationship (i.e., the changing value of one indicator inevitably results in the changing value of another) that exists between the dynamics particular to shares of output held by individual industries and characteristic to the processing industry's GVA on the one hand, and the change in share of GVA in the processing industry's output on the other:

$$\frac{q}{p}=\frac{q_1+q_2+\ldots+q_{17}}{p_1+p_2+\ldots+p_{17}}=\frac{q\left(\frac{q}{q}\right)\left(\frac{q_1}{q}+\frac{q_2}{q}+\ldots+\frac{q_{17}}{q}\right)}{p\left(\frac{p}{p}\right)\left(\frac{p_1}{p}+\frac{p_2}{p}+\ldots+\frac{p_{17}}{p}\right)}\rightarrow opt, \quad (1)$$

where:
q – the gross value added of the processing industry;
p – the output of the processing industry;
$q_1, q_2, ..., q_{17}$ – the gross value added of 17 industries of the processing industry;
$p_1, p_2, ..., p_{17}$ – the output of 17 industries of the processing industry;
$\frac{q_1}{q}, \frac{q_2}{q}, ..., \frac{q_{17}}{q}$ – the shares of 17 industries in GVA of the processing industry;
$\frac{p_1}{p}, \frac{p_2}{p}, ..., \frac{p_{17}}{p}$ – the shares of 17 industries in the output of the processing industry.

The target function of the optimisation is the increase in the actual value of share of GVA in the processing industry's output up to the desired level.

For an elaborated optimisation model (1), a set of criteria and constraints was defined as follows:

- The sum of the shares of individual 17 industries comprising the output and GVA structures of the processing industry is 1:

$$\frac{q_1}{q}+\frac{q_2}{q}+...+\frac{q_{17}}{q}=1;\quad \frac{p_1}{p}+\frac{p_2}{p}+...+\frac{p_{17}}{p}=1 \qquad (2)$$

- The values of share of GVA in output for each of the 17 industries of the processing industry should grow.

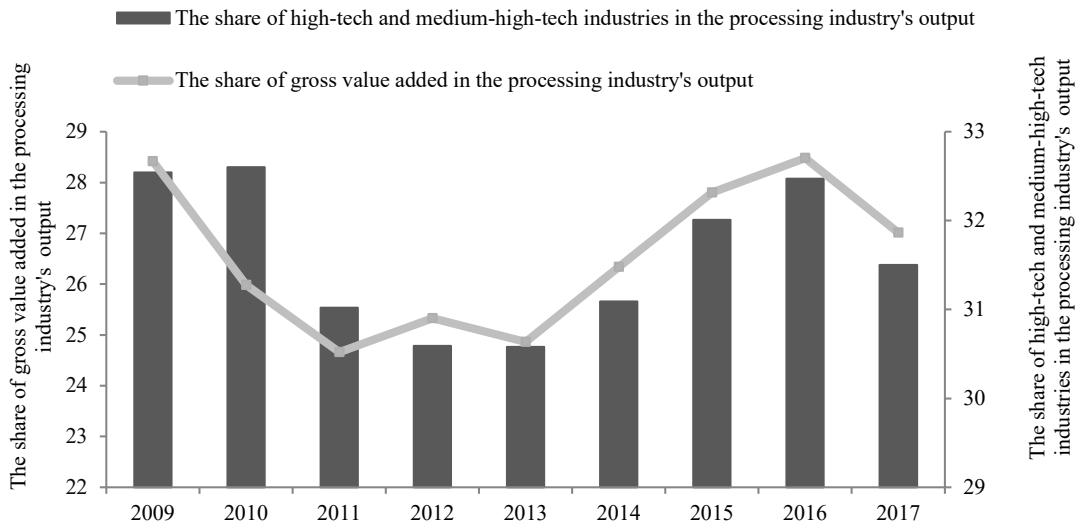


Fig. 1. Dynamics of structural indicators of the processing industry of Poland (%)
Source: elaborated by the authors based on Eurostat data.

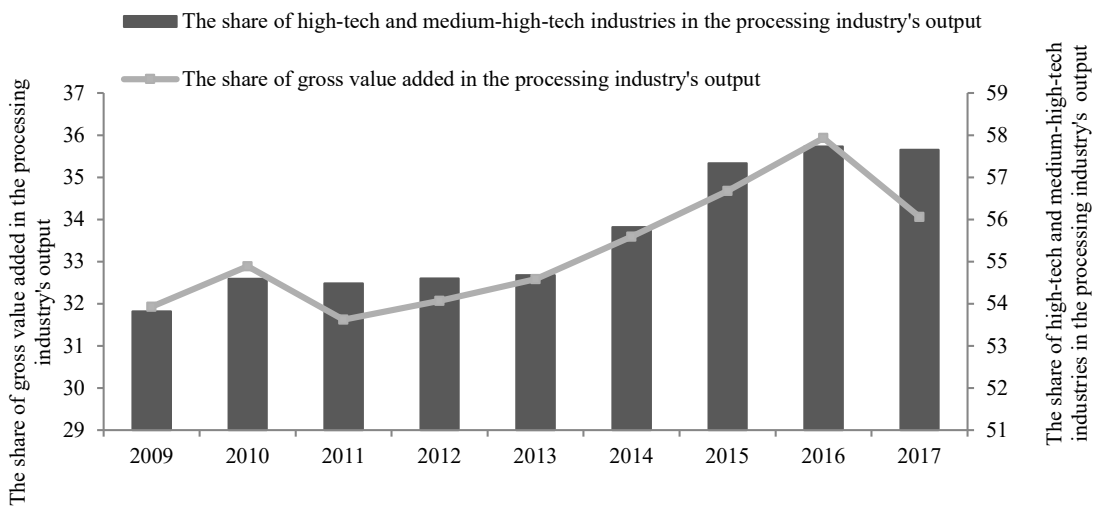
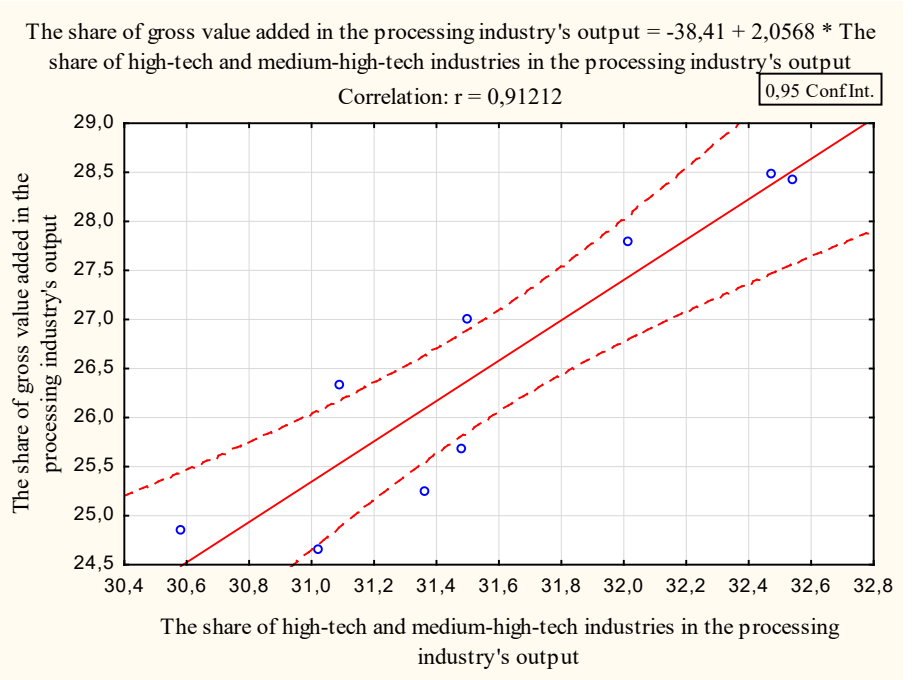


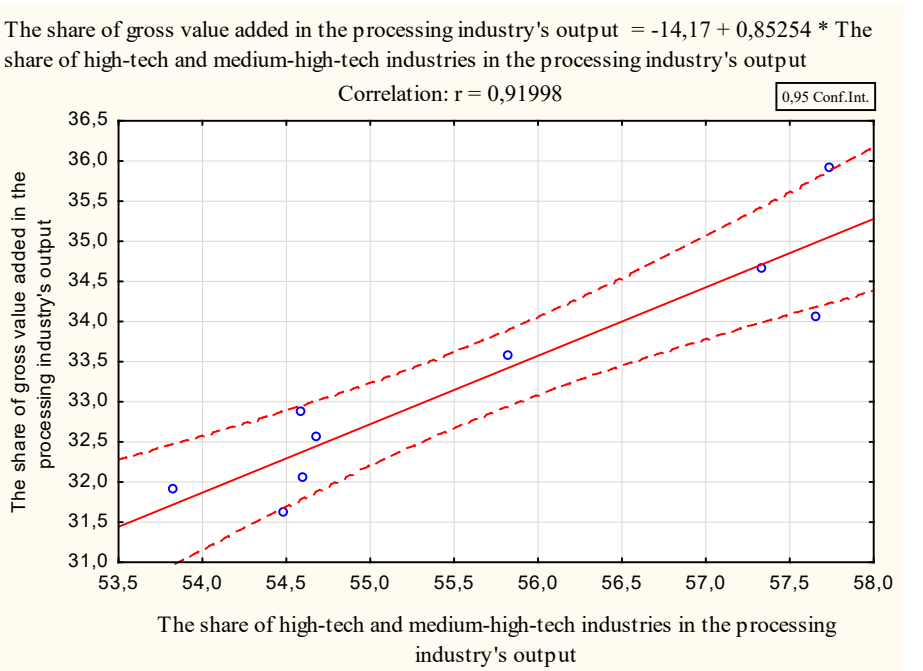
Fig. 2. Dynamics of structural indicators of the processing industry of Germany (%)
Source: elaborated by the authors based on Eurostat data.



Multiple R = 0.91212261; R^2= 0.83196765; Adjusted R^2= 0.80796303; Standard error of estimate: 0.654909995; F = 34.65865; df = 1.7; p = 0.000607; Intercept: -38.41398182; Std. Error: 11.02872; t(7) = -3.483; p = 0.0102

Fig. 3. Relationship between the share of high-tech and medium-high-tech industries in the processing industry's output and share of GVA in the processing industry's output in Poland

Source: elaborated by the authors based on Eurostat data.



Multiple R = 0.91998061; R^2= 0.84636433; Adjusted R^2= 0.82441638; Standard error of estimate: 0.599371375; F = 38.56234; df =1.7; p = 0.000441; Intercept: -14.16868929; Std. Error: 7.640436; t(7) = -1.854; p =0.1061

Fig. 4. Relationship between the share of high-tech and medium-high-tech industries in the processing industry's output and share of GVA in the processing industry's output in Germany

Source: elaborated by the authors based on Eurostat data.

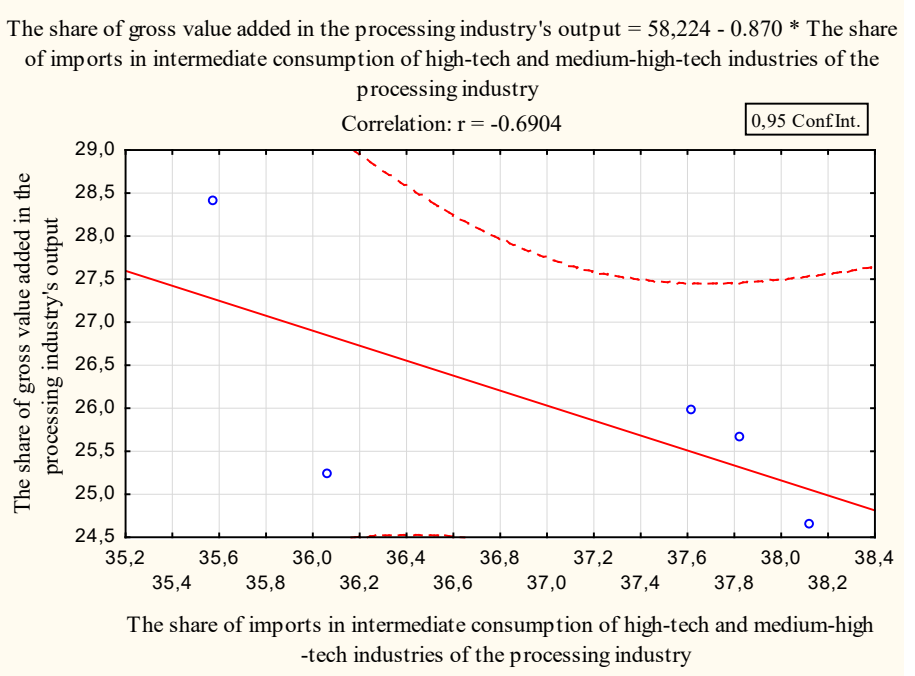
Tab. 3. Share of GVA in the processing industry's output and the share of imports in the intermediate consumption of the processing industry in Poland, the Czech Republic and Germany (%)

The group	Manufacturing	Code classification of economic activities ISIC Rev.4	Poland		Czech Republic		Germany	
			The share of gross value added in output	The share of imports in intermediate consumption	The share of gross value added in output	The share of imports in intermediate consumption	The share of gross value added in output	The share of imports in intermediate consumption
Medium-high and high technology	Computer, electronic and optical products	D26	18.57	46.74	18.94	53.13	47.07	35.89
	Chemicals and pharmaceutical products	D20T21	29.20	34.49	29.28	38.94	38.07	30.00
	Electrical equipment	D27	25.11	44.00	30.63	50.90	41.39	29.72
	Machinery and equipment, n.e.c.	D28	32.13	40.11	31.77	39.05	39.18	24.98
	Motor vehicles, trailers and semi-trailers	D29	20.95	34.73	19.43	47.95	32.35	24.83
	Other transport equipment	D30	30.40	49.04	36.38	38.86	34.21	35.45
	Total		**25.06**	**38.81**	**23.85**	**46.97**	**37.10**	**27.43**
Medium technology	Rubber and plastic products	D22	29.97	35.49	32.33	50.50	36.68	30.52
	Other non-metallic mineral products	D23	35.71	19.52	37.06	30.64	38.04	20.33
	Basic metals	D24	20.80	27.56	22.38	36.70	21.92	28.32
	Other manufacturing; repair and installation of machinery and equipment	D31T33	38.10	27.43	37.31	35.43	44.14	22.37
	Total		**32.40**	**28.53**	**32.12**	**40.09**	**34.43**	**26.30**
Low technology	Food products, beverages and tobacco	D10T12	24.41	15.32	26.17	24.95	25.16	21.13
	Textiles, wearing apparel, leather and related products	D13T15	36.58	33.57	33.66	46.29	32.92	29.01
	Wood and products of wood and cork	D16	29.35	15.24	27.78	20.10	28.36	17.87
	Paper products and printing	D17T18	31.08	25.75	28.48	36.28	33.31	23.39
	Coke and refined petroleum products	D19	14.37	53.3	5.27	77.86	10.61	55.77
	Fabricated metal products	D25	36.99	33.47	35.72	39.27	43.17	23.79
	Total		**27.33**	**25.99**	**28.44**	**37.38**	**29.86**	**27.39**
	Total processing industry		**27.81**	**30.82**	**26.60**	**43.37**	**34.79**	**27.22**

Source: elaborated by the authors based on OECD data.

- The shares of high-tech and the medium-high-tech industries in the processing industry's output and GVA should grow.

In some EU countries, high-tech industries are not sufficiently effective. These are, in particular, the Czech Republic, Hungary, Slovenia and Slovakia — countries with a high level of import dependence characteristic to the processing industry. In the Czech Republic, despite a high share of high-tech and medium-tech industries within the structure of the processing industry (56.30% in 2017), their share of GVA in output was only 26.82%. In this country, in-depth studies found a relatively high (43.37%) share of imports in intermediate consumption of the processing industry, including high-tech and medium-high-tech industries, which amounted to 46.97% in 2015 (this being the last year, for which the shares of imports in the intermediate consumption of processing industries of EU countries were available). In Poland, these indicators were, respectively, 30.82%



Multiple R: 0.69041263; R^2: 0.47666960; adjusted R^2: 0.30222614; Standard error of estimate: 1.203776159; Intercept: 58.224202892; Std. Error: 19.50324; t(3) = 2.9854; p = 0.196895; p < 0.0583; df = 1.3

Fig. 5. Relationship between share of GVA in the processing industry's output and the share of imports in the intermediate consumption of high-tech and medium-high-tech industries in Poland

Source: elaborated by the authors based on OECD data.

and 38.81%, and in Germany, 27.22% and 27.43% (Table 3)[1].

According to Table 3, the smaller is the share of imports in the intermediate consumption (primarily of high-tech and medium-high-tech industries), the higher is share of GVA in the processing industry's output.

Results of the correlation and regression analysis confirmed the presence of a stochastic connection and inverse relationship between the change in share of GVA in the processing industry's output and the share of high-tech and medium-high-tech industries in all three studied countries. However, the degree of dependency between these indicators varied from country to country. This relationship was very high in the Czech Republic (the correlation coefficient was -0.92), high in Poland (-0.69), and low in Germany (-0.17) (Figs. 5–7). Determination coefficients show that the dependence of share of GVA in the processing industry's output on the share of imports in the intermediate consumption of high-tech and medium-high-tech industries amounts to 84.04% in the Czech Republic, 47.67% in Poland, and as little as 2.94% in Germany.

Thus, the results of the analysis confirmed the second hypothesis: the lower is the share of imports in the intermediate consumption of high-tech and medium-high-tech industries, the higher is share of GVA in the processing industry's output.

Consequently, the optimised structure of the intermediate consumption of the processing industry in favour of the domestic components of high-tech and medium-high-tech industries increases the efficiency of the processing industry.

The functional relationship between share of GVA in the processing industry's output and the structure (in terms of domestic and imported components) of the intermediate consumption is represented by the optimisation model:

$$\frac{q}{p} = \frac{q_1 + q_2 + \ldots + q_{16}}{q_1 + c_1\left(\frac{d_1}{c_1} + \frac{i_1}{c_1}\right) + q_2 + c_2\left(\frac{d_2}{c_2} + \frac{i_2}{c_2}\right) + \ldots + q_{16} + c_{16}\left(\frac{d_{16}}{c_{16}} + \frac{i_{16}}{c_{16}}\right)} \rightarrow opt, \quad (3)$$

[1] The names, codes and groups of industries within the processing industry listed in Table 3 correspond to the ISIC Rev.4 economic activity classification system. This decision was made because the fullest body of information, which was required to calculate the share of imports in intermediate consumption of industries within the processing industry, was available from OECD (2019), where it was given according to the named system. The manufacturability groups were formed according to the levels of the technological intensity of ISIC Rev.4 UNIDO (2019). It should also be noted that Furniture production (Division 31) was classified as Medium rather than Low technology, as required by UNIDO (2019). This decision was made because the OECD (2019) information concerning the imports of intermediate consumption of Furniture (Division 31) was presented in D31T33: Other manufacturing; repair and installation of machinery and equipment.

where:

q – the gross value added of the processing industry;

p – the output of the processing industry;

$q_1, q_2, ..., q_{16}$ – the gross value added of 16 industries of the processing industry;

$c_1, c_2, ..., c_{16}$ – intermediate consumption of the 16 industries;

$\frac{d_1}{c_1}, \frac{d_2}{c_2}, ..., \frac{d_{16}}{c_{16}}$ – the shares of domestic components in the intermediate consumption of each of the 16 industries;

$\frac{i_1}{c_1}, \frac{i_2}{c_2}, ..., \frac{i_{16}}{c_{16}}$ – the shares of imported components in the intermediate consumption of each of the 16 industries.

The target function of the optimisation was to increase the actual share of GVA in the processing industry's output to the desired level.

The following limitations and criteria were defined for the optimisation function (2):

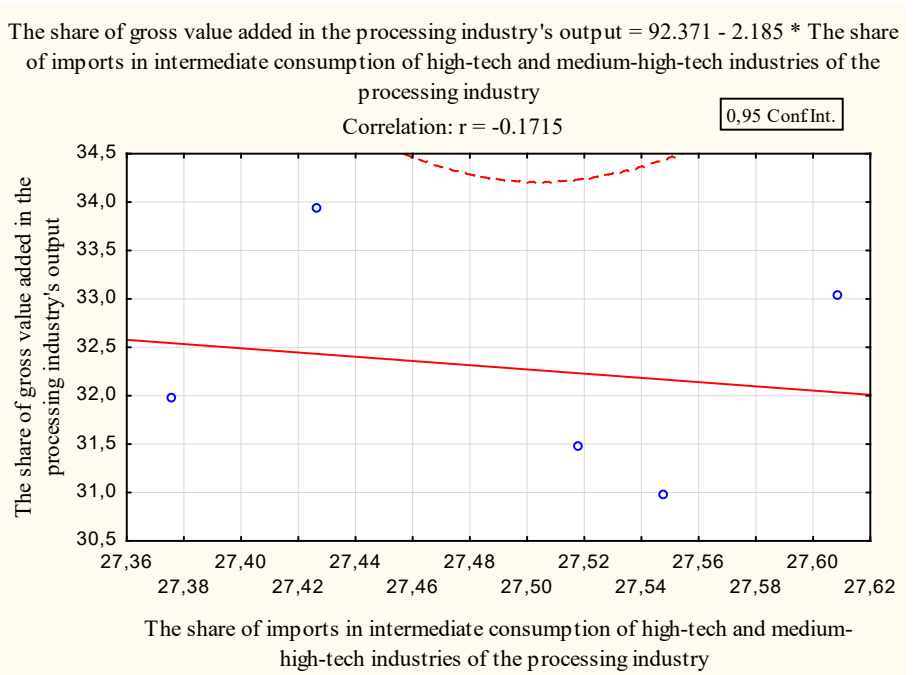
1. The total sum of the shares of domestic and imported components of the intermediate consumption for each of the 16 industries is 1:

$$\left(\frac{d_1}{c_1}+\frac{i_1}{c_1}\right)=1,\ \left(\frac{d_2}{c_2}+\frac{i_2}{c_2}\right)=1,\ldots,\ \left(\frac{d_{16}}{c_{16}}+\frac{i_{16}}{c_{16}}\right)=1 \quad (4)$$

- The volumes of GVA and the output of the processing industry are equal to the sums of the GVAs and outputs of the 16 industries.
- The share of domestic components in the intermediate consumption of high-tech and medium-high-tech industries is inclined to grow, while the share of imported components — to decline.
- Shares of GVA in output for each of high-tech and medium-high-tech industries should increase.

2. RESULTS

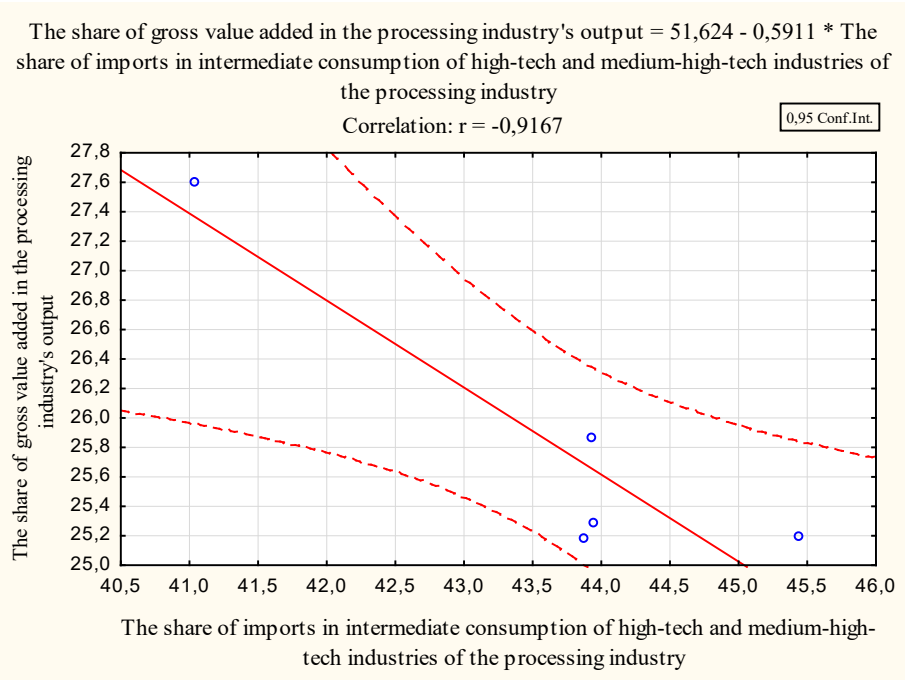
The optimisation model (1) was solved using the linear programming method. The input data for calculations were the values of structural indices of the processing industry in Poland. The target function was to achieve 34.06% (Germany's value) in terms of share of GVA in the processing industry's output in Poland. As a result of the calculations, the optimised structures of output and GVA for the processing industry in Poland were obtained (Table 4).



Multiple R: 0.17154493; R^2: 0.02942766; adjusted R^2: -0.29409645; Standard error of estimate: 1.360032654; Intercept: 92.370829663; Std. Error: 199.2361; F = 0.0909597; t(3) = 0.46363; p = 0.782658; p < 0.6745; df = 1,3

Fig. 6. Relationship between share of GVA in the processing industry's output and the share of imports in the intermediate consumption of high-tech and medium-high-tech industries in Germany

Source: elaborated by the authors based on OECD data.



Multiple R: 0.91671400; R^2:0,84036455; adjusted R^2: 0.78715273; Standard error of estimate: 0.475927705; Intercept: 51.624065020; Std. Error: 6.494768; F = 15.79282; p = 0.028490; p < 0.0042; t(3) = 7.9486; df = 1.3

Fig. 7. Relationship between share of GVA in the processing industry's output and the share of imports in the intermediate consumption of high-tech and medium-high-tech industries in the Czech Republic

Source: elaborated by the authors based on OECD data.

Tab. 4. Optimised structures of GVA and output for the processing industry in Poland (%)

THE GROUP	THE MANUFACTURING	CLASSIFICATION CODE OF ECONOMIC ACTIVITIES NACE REV.2	THE GROSS VALUE ADDED STRUCTURE	THE OUTPUT STRUCTURE	THE SHARE OF GROSS VALUE ADDED IN OUTPUT
The high-tech	Manufacture of basic pharmaceutical products and pharmaceuticals	C21	2.22	1.54	49.01
	Manufacture of computers, electronic and optical products	C26	4.02	3.42	40.00
	Total		**6.23**	**4.96**	**42.80**
The medium-high-tech	Manufacture of chemicals and chemical products	C20	6.13	5.50	37.96
	Production of electric equipment	C27	5.83	4.97	39.98
	Manufacture of machinery and equipment not elsewhere classified	C28	4.91	4.51	37.05
	Production of motor vehicles, trailers and semitrailers	C29	13.27	13.74	32.89
	Manufacture of other transport equipment	C30	2.43	2.52	32.87
	Total		**32.57**	**31.24**	**35.51**
The moderately-low-tech	Production of coke and coke products of oil refining	C19	2.99	5.29	19.25
	Manufacture of rubber and plastic products	C22	7.43	7.24	34.96
	Manufacture of other non-metallic mineral products	C23	4.64	4.37	36.17
	Metallurgical production	C24	2.37	4.22	19.13
	Manufacture of fabricated metal products, except machinery and equipment	C25	8.86	7.40	40.78
	Repair and installation of machinery and equipment	C33	4.77	3.00	54.21
	Total		**31.07**	**31.52**	**36.46**

The low-tech	Manufacture of food products; beverages and tobacco products	C10-12	15.08	19.01	27.01
	Manufacture of textiles, wearing apparel, leather and related products	C13-15	2.31	2.20	35.78
	Manufacture of wood, paper, printing and reproduction	C16-18	7.64	7.20	36.12
	Manufacture of furniture; other manufacturing	C31-32	5.11	3.87	44.97
	Total		**30.13**	**32.28**	**31.79**
Total processing industry			**100.00**	**100.00**	**34.06**

Source: elaborated by the authors based on Eurostat data.

According to the results, the processing industry in Poland will be able to reach the German level of efficiency (the share of GVA in output at the level of 34.06%) on the condition that the share of high-tech and medium-high-tech industries in the output structure will increase by 4.69 pp. At the same time, share of GVA of high-tech and medium-high-tech industries in the processing industry's GVA should increase by 11.02 pp in Poland.

The optimisation model (2) was solved using the linear programming method. The initial data for the calculations were the values of structural indicators of the Czech processing industry. The target function was to achieve 34.79% for share of GVA in the processing industry's output in the Czech Republic (which is the indicator for Germany in 2015). According to the simulation results, an optimised structure of the intermediate consumption of the Czech processing industry was constructed (Table 5).

Thus, ratios were determined between the share of domestic and imported components of the intermediate consumption for all 16 industries, at which the level of efficiency of the Czech processing industry would reach the level of Germany in 2015 (share of GVA in output amounting to 34.79%). Such an efficiency indicator can be achieved under the condition that the import share in the intermediate consumption of high-tech and medium-high industries of the Czech processing industry is decreased by 18.49 pp.

Conclusions

The study into the industrial sector of the EU economy, in particular Poland and Germany, suggested a relationship between the efficiency of the processing industry and its structure. The results of the correlation and regression analysis proved the adequacy of the hypothesis stating that the higher was the share of high-tech and medium-high-tech industries of the processing industry's output, the higher was share of GVA in output of these types of industrial activity. This led to the conclusion that the optimisation of the processing industry's output structure was a way to increase the efficiency of this industry. Based on this statement, an optimisation model was constructed, in which the target function was to increase share of GVA in the processing industry's output to the desired level, and the main optimisation criterion was increasing the share of high-tech and medium-high-tech industries in the output structure.

Further research found that the high-tech processing industry was not always effective. This particularly applies to such countries as the Czech Republic, Hungary, Slovenia and Slovakia, i.e. countries with a high level of import dependence in the processing industry. The results of the correlation and regression analysis, conducted on the example of the Czech Republic, proved the adequacy of the second hypothesis stating that the lower was the share of imports in the intermediate consumption of high-tech and medium-tech industries, the higher was the share of GVA in the processing industry's output. Hence, another way for increasing the efficiency of the processing industry was defined as the optimisation of the structure pertaining to the intermediate consumption of high-tech and medium-high-tech industries. According to this hypothesis, an optimisation model was developed, which allowed determining ratios between domestic and imported components in the structure of the intermediate consumption of the industries within the processing industry, that would allow achieving the desired level of efficiency.

The developed economic and mathematical models were solved using the method of linear programming. In both models, the share of GVA in the German processing industry's output as a benchmark was chosen as the target function. The first model was tested on the example of Poland, in particular, the

Tab. 5. Optimised structure (in terms of domestic and imported components) of the intermediate consumption of the processing industry in the Czech Republic (%)

THE GROUP	THE MANUFACTURING	CODE CLASSIFICATION OF ECONOMIC ACTIVITIES ISIC REV.4	ACTUAL DATA (2015)			OPTIMISED DATA		
			THE SHARE OF GROSS VALUE ADDED IN OUTPUT	THE SHARE OF DOMESTIC COMPONENT IN INTERMEDIATE CONSUMPTION	THE SHARE OF IMPORTED COMPONENT IN INTERMEDIATE CONSUMPTION	THE SHARE OF GROSS VALUE ADDED IN OUTPUT	THE SHARE OF DOMESTIC COMPONENT IN INTERMEDIATE CONSUMPTION	THE SHARE OF IMPORTED COMPONENT IN INTERMEDIATE CONSUMPTION
Medium-high and high technology	Computer, electronic and optical products	D26	18.94	46.87	53.13	20.12	64.64	35.36
	Chemicals and pharmaceutical products	D20T21	29.28	61.06	38.94	32.21	65.92	34.08
	Electrical equipment	D27	30.63	49.10	50.90	31.21	65.44	34.56
	Machinery and equipment, n.e.c.	D28	31.77	60.95	39.05	33.21	66.60	33.40
	Motor vehicles, trailers and semi-trailers	D29	19.43	52.05	47.95	22.21	77.56	22.44
	Other transport equipment	D30	36.38	61.14	38.86	38.21	64.17	35.83
	Total		**23.85**	**53.03**	**46.97**	**26.06**	**71.52**	**28.48**
The moderately-low-tech	Rubber and plastic products	D22	5.27	22.14	77.86	7.39	23.79	76.21
	Other non-metallic mineral products	D23	32.33	49.50	50.50	35.51	64.35	35.65
	Basic metals	D24	37.06	69.36	30.64	52.38	71.80	28.20
	Other manufacturing; repair and installation of machinery and equipment	D31T33	22.38	63.30	36.70	42.07	64.50	35.50
	Total		**35.72**	**60.73**	**39.27**	**37.41**	**76.40**	**23.60**
The low-tech	Food products, beverages and tobacco	D10T12	29.95	54.85	45.15	36.84	64.14	35.86
	Textiles, wearing apparel, leather and related products	D13T15	26.17	75.05	24.95	42.71	77.67	22.33
	Wood and products of wood and cork	D16	33.66	53.71	46.29	36.55	56.04	43.96
	Paper products and printing	D17T18	27.78	79.90	20.10	29.89	80.44	19.56
	Coke and refined petroleum products	D19	28.48	63.72	36.28	31.64	64.37	35.63
	Fabricated metal products	D25	37.31	64.57	35.43	38.20	67.43	32.57
	Total		**30.11**	**69.83**	**30.17**	**37.85**	**71.15**	**28.85**
Total processing industry			**26.60**	**56.63**	**43.37**	**34.79**	**74.97**	**25.03**

Source: elaborated by the authors based on OECD data.

optimised structures of the output and GVA of the processing industry of this country were built according to the criterion of increasing the technological level. The second model was tested on the example of the Czech Republic, in particular, the optimised structure of the intermediate consumption of the industries was built according to the criterion of reducing import dependence.

Further research in this direction will focus on modelling the impact of other factors on the level of processing industry's efficiency, in particular, the specificities of the high-tech industries from the perspective of the creation of value-added chains.

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