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Assessing the productivity of Serbian manufacturing industry with Malmquist DEA indices

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Abstract*: The subject of this paper is the productivity of the manufacturing industry of Serbia. The analysis was conducted on data for 85 manufacturing groups of Serbian industry during the period 2012-2022. Changes in total factor productivity, as well as the decomposition of these changes into technological changes and innovations on the one hand, and efficiency changes on the other, were estimated using Malmquist indices calculated by DEA program. The introduction offers a brief overview of the macroeconomic context in which industrial production takes place. The second chapter is devoted to the methodology and the presentation of the data used. In the third part of the paper, the results of the research are presented. The total factor productivity of the manufacturing industry grew at a low average rate of about 0.5% annually. The manufacturing industry lacks continuity of growth, with no more than two years of consecutive productivity growth recorded. The best results were achieved in the manufacture of coke and refined petroleum products, electrical equipment and other transport equipment. Productivity growth in these divisions is rather the result of efficiency improvements than technological changes, i.e. innovations. The biggest decline was achieved in the manufacture of basic iron and steel.*

Keywords*: total factor productivity, manufacturing industry, efficiency, technological change, Malmquist indices, DEA program.*

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Ocena produktivnosti prerađivačke industrije Srbije Malmkvistovim DEA indeksima

***Apstrakt**: Predmet ovog rada je ocena produktivnosti pojedinačnih oblasti i grana prerađivačke industrije Srbije. Analiza je sprovedena na podacima za 85 grana prerađivačke industrije tokom perioda od 2012. do 2022. godine. Promene ukupne faktorske produktivnosti, kao i dekompozicija ovih promena na tehnološke promene i inovacije sa jedne strane i promene efikasnosti sa druge strane, izračunate su pomoću Malmkvistovih indeksa. Za kalkulaciju je korišćen DEA program. U uvodu rada je napravljan kratak osvrt na makroekonomski kontekst u okviru koga se odvija industrijska proizvodnja. Drugo poglavlje posvećeno je objašnjenju korišćene metodologije i prikazu korišćenih podataka. U trećem delu rada prezentovani su i komentarisani rezultati istraživanja. Ukupna faktorska produktivnost prerađivačke industrije u posmatranom periodu rasla je po skromnoj stopi od oko 0,5% prosečno godišnje. Prerađivačkoj industriji nedostaje kontinuitet rasta, s obzirom da je zabeleženo najviše dve godine uzastopnog rasta produktivnosti. Najbolji rezultati ostvareni su u proizvodnji koksa i derivata nafte, proizvodnji električne opreme i proizvodnji ostalih saobraćajnih sredstava. Rast produktivnosti u ovim granama je više rezultat rasta efikasnosti pri postojećoj tehnologiji, nego tehnoloških promena, odnosno inovacija. Najveći pad ostvaren je u proizvodnji sirovog gvožđa, čelika i ferolegura.*

***Ključne reči**: ukupna faktorska produktivnost, prerađivačka industrija, efikasnost, tehnološke promene, Malmkvistovi indeksi, DEA program.*

1. Introduction

Geopolitical tensions generally create uncertainty, and borrowing costs reflect the end of a relatively long and favorable economic cycle, leaving less room for investment and consumption. These factors make the current global environment unfavorable to Serbia's industrial policy. The present crisis is distinct from the pandemic issue in terms of causes (political vs. health) and interests. It has persisted since at least 2020 and has been exacerbated by the Ukrainian conflict.

Once the disruption caused by the pandemic is removed, it can be said that the current economic model is producing demonstrable results in terms of economic growth. Serbia has recorded good growth rates since 2015 despite uneven fluctuations. In other words, there are basic requirements for progress. Nevertheless, economic development is questionable in many respects. These include an export structure dominated by exports of basic industrial metals, agricultural products, and low-value manufactured goods, supply chains that are not fully engaged with the domestic small business economic sector, distribution of economic activity by country region where economic and demographic activity is concentrated, etc. (Nikolić, 2023).

All open economies depend on international economic flows for the profitability of production and implementation in domestic and international markets. The stagnation trend in the euro area reduces the scope for increased exports and inflows of foreign direct investment. There are two ways to increase exports in accordance with international demand and competitiveness. That is, increasing the scale of existing production activities and/or gradually expanding higher value-added production capacity. The problem faced by many export companies is that they rely on a raw material base or import many components to manufacture products for export. (Nikolić & Nikolić, 2023).

Serbia's most important manufacturing branches are the metal and chemical industries, which together account for about three-fifths of exports. On the other hand, although almost all major export companies are majority-owned by foreign capital, it is reasonable to emphasize that their interests are primarily market-oriented. Improving industrial capacity requires a systematic approach. In this sense, the Industrial Policy Strategy and Smart Specialization Strategy of the Republic of Serbia are considered important strategic documents for the period 2021-2030. Priority is given to the food industry and the metal industry (with emphasis on the automotive industry and the production of devices, machinery and systems). Until now, government policy has been to attract as much investment as possible in order to employ more people and reduce high unemployment rates. This will fall to around 9% in 2023, so the new priority for investment attraction policy is to focus on higher value-added investments. (Ministry of Education, Science and Technological Development of the Republic of Serbia, 2019 & Ministry of Economy of the Republic of Serbia, 2020).

In this sense, this paper provides a more detailed insight into the changes in productivity and efficiency of the Serbian industry during the past decade at the level of manufacturing groups.

2. Methodology and data

The methodology applied in this paper is based on the approach to the analysis of productivity growth, technical progress and efficiency change defined and applied by Färe et al. (1994). This approach allows the measurement of total factor productivity changes, but also a decomposition of productivity changes into changes of efficiency, i.e., catching up with efficiency frontier of the existing technology, as well as changes in technology, i.e., innovation. The productivity change is calculated as the geometric mean of two Malmquist indices, the quantity indices constructed as ratios of distance functions.

According to Färe et al. (1994), the production technology S^t, which transforms inputs x^t into outputs y^t, can be written as follows:

$$S^t = \{(x^t, y^t): x^t can\ produce\ y^t\} \tag{1}$$

The output distance function at time period t is defined as follows:

$$D_0^t(x^t, y^t) = inf\{\theta: (x^t, y^t/\theta) \in S^t\} \tag{2}$$

where $D_0^t \leq 1$ if and only if $(x^t, y^t) \in S^t$. In addition, $D_0^t = 1$ if and only if (x^t, y^t) is on the frontier of technology which occurs when production is technically efficient.

In order to define the Malmquist index, Färe et al. (1994) also defined the distance function measuring the maximal proportional change in outputs required to make (x^{t+1}, y^{t+1}) feasible in relation to technology at time period t (the production (x^{t+1}, y^{t+1}) is not feasible at time period t considering the technological change):

$$D_0^t(x^{t+1}, y^{t+1}) = inf\{\theta: (x^{t+1}, y^{t+1}/\theta) \in S^t\} \tag{3}$$

The Malmquist production index can be calculated as follows:

$$M^t = \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \tag{4}$$

considering the technology at time period t as the reference technology, or:

$$M^{t+1} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \tag{5}$$

considering the technology at time period t+1 as the reference technology.

Färe et al. (1994) calculated the output-based Malmquist productivity change index as the geometric mean of two above defined Malmquist indices, defined by formulas (4) and (5):

$$M_0(x^t, y^t, x^{t+1}, y^{t+1}) = \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\right) \times \left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \tag{6}$$

Furthermore, the Malmquist productivity change index can be written also as follows:

$$M_0(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right) \times \left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \tag{7}$$

where:

$$\frac{D_0^{t+1}(x^{t+1},y^{t+1})}{D_0^{t}(x^{t},y^{t})} \tag{8}$$

represents changes in relative efficiency (EFFCH), while

$$\left[\left(\frac{D_0^{t}(x^{t+1},y^{t+1})}{D_0^{t+1}(x^{t+1},y^{t+1})}\right)\times\left(\frac{D_0^{t}(x^{t},y^{t})}{D_0^{t+1}(x^{t},y^{t})}\right)\right]^{\frac{1}{2}} \tag{9}$$

represents changes in technology between two observed periods (TECHCH).

Therefore, the equation (7) can be abbreviated as:

$$M_0(x^t, y^t, x^{t+1}, y^{t+1}) = TECHCH \times EFFCH \tag{10}$$

The value of the Malmquist productivity change index greater than 1 indicates growth of total factor productivity from the period t to the period t+1.

In this paper, the above defined indices are calculated by the computer program written to carry out the data envelopment analysis (DEA), as described by Coelli (1996). In order to calculate the necessary indices by using DEA, the following four linear programming problems have to be solved (Coelli, 1996):

$$[d_o^t(y_t, x_t)]^{-1} = max_{\phi,\lambda}\,\phi$$

where:

$$-\phi y_{it} + Y_t\lambda \geq 0,$$
$$x_{it} - X_t\lambda \geq 0,$$
$$\lambda \geq 0, \tag{11}$$

$$[d_o^{t+1}(y_{t+1}, x_{t+1})]^{-1} = max_{\phi,\lambda}\,\phi$$

where:

$$-\phi y_{i,t+1} + Y_{t+1}\lambda \geq 0,$$
$$x_{i,t+1} - X_{t+1}\lambda \geq 0,$$
$$\lambda \geq 0, \tag{12}$$

$$[d_o^{t}(y_{t+1}, x_{t+1})]^{-1} = max_{\phi,\lambda}\,\phi$$

where:

$$-\phi y_{i,t+1} + Y_t\lambda \geq 0,$$
$$x_{i,t+1} - X_t\lambda \geq 0,$$
$$\lambda \geq 0, \tag{13}$$

$$[d_o^{t+1}(y_t, x_t)]^{-1} = max_{\phi,\lambda}\,\phi$$

where:

$$-\phi y_{it} + Y_{t+1}\lambda \geq 0,$$
$$x_{it} + X_{t+1}\lambda \geq 0,$$
$$\lambda \geq 0, \quad (14)$$

where X and Y represent the vectors of inputs and outputs, t and t+1 refer to different time periods, i refers to the industry branch, while ϕ is a scalar and λ represents the vector of constants.

Furthermore, according to Färe et al. (1994), based on Farell (1957), the further decomposition of the Malmquist productivity change index is also possible as follows:

$$M_0(x^t, y^t, x^{t+1}, y^{t+1}) = TECHCH \times PECH \times SECH \quad (15)$$

where PECH represents pure efficiency change and SECH represents scale efficiency change. The SECH refers to efficiency change calculated under constant returns to scale, while PECH is related to efficiency change calculated under variable returns to scale.

The Malmquist productivity indices have been used in many different analyses for years, including recent analyses related to some divisions of Serbian manufacturing industry (Savović et al., 2021).

Despite its many advantages, the applied methodology could also have a few drawbacks. Pastor & Lovell (2005) emphasized that the geometric mean Malmquist productivity indices are not circular and they propose the global Malmquist productivity index which is circular and immune to linear program infeasibility. Cheng et al. (2015) note that DEA is a non-parametric method capable of handling multiple outputs and inputs, but it does not consider uncertainty in observations. Therefore, they construct a Malmquist productivity index based on stochastic non-parametric envelopment of data method, StoNED.

Our sample consists of 85 manufacturing groups of Serbian manufacturing industry, as presented in Table 1:

Table 1. The manufacturing groups of Serbian manufacturing industry

Code	Manufacturing division	Number of groups
10	Manufacture of food products	9
11	Manufacture of beverages	1
12	Manufacture of tobacco products	1
13	Manufacture of textiles	3
14	Manufacture of wearing apparel	2
15	Manufacture of leather and related products of other materials	2
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	2
17	Manufacture of paper and paper products	2
18	Printing and reproduction of recorded media	1
19	Manufacture of coke and refined petroleum products	1
20	Manufacture of chemicals and chemical products	6
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	2
22	Manufacture of rubber and plastic products	2
23	Manufacture of other non-metallic mineral products	8
24	Manufacture of basic metals	5
25	Manufacture of fabricated metal products, except machinery and equipment	6
26	Manufacture of computer, electronic and optical products	7
27	Manufacture of electrical equipment	6
28	Manufacture of machinery and equipment n.e.c.	5
29	Manufacture of motor vehicles, trailers and semi-trailers	3
30	Manufacture of other transport equipment	4
31	Manufacture of furniture	1
32	Other manufacturing	6

Source: Authors

The analysis covers the period from 2012 to 2022. The output variables include gross value added, as well as combined gross value added and net exports (coverage of imports by exports). The input variables include labor and capital. Labor is measured by earning costs, while capital was measured by its value. The sources of these data include databases of the Statistical Office of the Republic of Serbia (2023). The same methodology as in our variant 1 (one output and two inputs) was applied by Halkos & Tzeremes (2006), while the same methodology as in our variant 2 (with both more than one output and more than one input) was applied by Wang et al. (2020).

In Table 2, descriptive statistics of the used variables is shown.

Table 2. Descriptive statistics

Variable		Mean	Std. Dev.	Min	Max	Observations	
year	overall	2017	3,2	2012	2022	N×T =	935
	between		3,3	2012	2022	T =	11
	within		0,0	2017	2017	N =	85
code	overall	225,5	66,7	101,0	329,0	N×T =	935
	between		0,0	225,5	225,5	T =	11
	within		66,7	101,0	329,0	N =	85
K	overall	154.907,4	258.995,6	35,2	3.101.854,0	N×T =	935
	between		47.496,3	97.350,8	243.285,4	T =	11
	within		255.001,4	-88.342,2	3.013.476,0	N =	85
L	overall	35.021,9	46.543,2	12,5	612.259,0	N×T =	935
	between		10.617,2	24.551,8	55.368,5	T =	11
	within		45.427,8	-20.331,2	591.912,4	N =	85
VA	overall	65.192,5	94.617,1	1,0	1.322.993,0	N×T =	935
	between		19.842,6	47.447,6	109.011,6	T =	11
	within		92.704,3	-43.814,4	1.279.174,0	N =	85
E/I ratio	overall	109,9	204,9	2,0	2.583,5	N×T =	935
	between		14,6	90,4	130,4	T =	11
	within		204,4	-17,5	2.563,0	N =	85

Source: Statistical Office of the Republic of Serbia (2023)

Considering the linear programming problems defined by equations from (11) to (14) for two time periods, as well as our sample size, according to Coelli (1996), N×(3T-2) linear programming problems have to be defined and solved, i.e.2635 problems. Furthermore, considering further decomposition of the productivity change index defined by equation (15), N×(4T-2) linear programming problems have to be defined and solved, i.e.3570 problems, which was done by using the computer DEAP program described by Coelli (1996).

3. Results and discussion

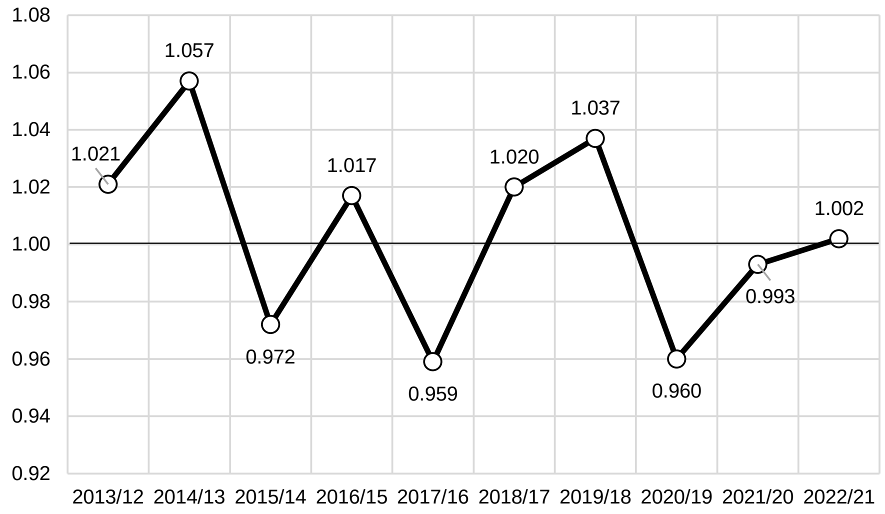
The total factor productivity is considered as a key yardstick of economic performance (Schreyer & Pilat, 2001). The changes of total factor productivity in Serbian manufacturing industry as a whole are presented in Figure 1.

The value of the Malmquist index greater than one for some year means that the total factor productivity increased in that year as compared to the previous year. On the other hand, the value smaller than one means that the total factor productivity decreased in that year as compared with the previous year.

For example, the value of the index for 2022/21 of 1.002 means that the total factor productivity in 2022 was by 0,2% greater than in 2021, while the value for 2021/20 of 0.993 means that the total factor productivity in 2021 was by 0.7% smaller than in 2020.

Variant 1 refers to the model with one single output measured by gross value added, and labor and capital as two inputs.

Figure 1. Total factor productivity changes in Serbian manufacturing industry, measured by Malmquist indices, 2012-2022 (variant 1)



Source: Authors' calculation

Based on the results presented above, it can be noticed that there has not been continuity in the growth of total factor productivity in Serbian manufacturing industry as a whole in the observed period, given that a maximum of two consecutive years of total factor productivity growth have been recorded. The highest growth rates were in 2014 and 2019 amounting to 5.7% and 3.7% respectively. On the other hand, the highest declines were in 2017 and 2020, amounting to around 4% each.

In Table 3, the structure of total factor productivity changes (TFPCH) is shown. As explained in the methodological part of the paper, total factor productivity change is divided into changes in relative efficiency (EFFCH) and changes in technology (TECHCH), while changes in relative efficiency are further divided into pure efficiency change under variable returns to scale (PECH) and scale efficiency change under constant returns to scale (SECH).

The results are presented for the each year within the observed period, but also as a geometric mean for the entire observed period. According to the mean results, the total factor productivity has been increasing by the average annual growth rate of 0.3% in the observed period. Given the presented structure, the quite low positive changes of productivity have been driven mostly by the technological progress, which is in line with the findings on technical improvements in manufacturing stimulated by foreign direct investments (Nikolić, 2021).

Table 3. Changes in productivity, efficiency and technological progress of Serbian manufacturing industry, measured by Malmquist indices, 2012-2022 (variant 1)

Years	**EFFCH**	**TECHCH**	**PECH**	**SECH**	**TFPCH**
2013/2012	0.809	1.262	0.869	0.930	1.021
2014/2013	0.795	1.330	1.064	0.748	1.057
2015/2014	0.954	1.018	0.958	0.996	0.972
2016/2015	1.255	0.810	0.827	1.518	1.017
2017/2016	1.147	0.836	1.182	0.970	0.959
2018/2017	1.153	0.885	1.144	1.007	1.020
2019/2018	0.967	1.073	0.839	1.152	1.037
2020/2019	0.883	1.087	0.883	1.000	0.960
2021/2020	1.170	0.849	1.285	0.911	0.993
2022/2021	0.985	1.017	1.125	0.876	1.002
MEAN	**1.000**	**1.003**	**1.006**	**0.994**	**1.003**

Source: Authors' calculation

The changes of total factor productivity in Serbian manufacturing industry as a whole, in variant 2, are presented in Figure 2.

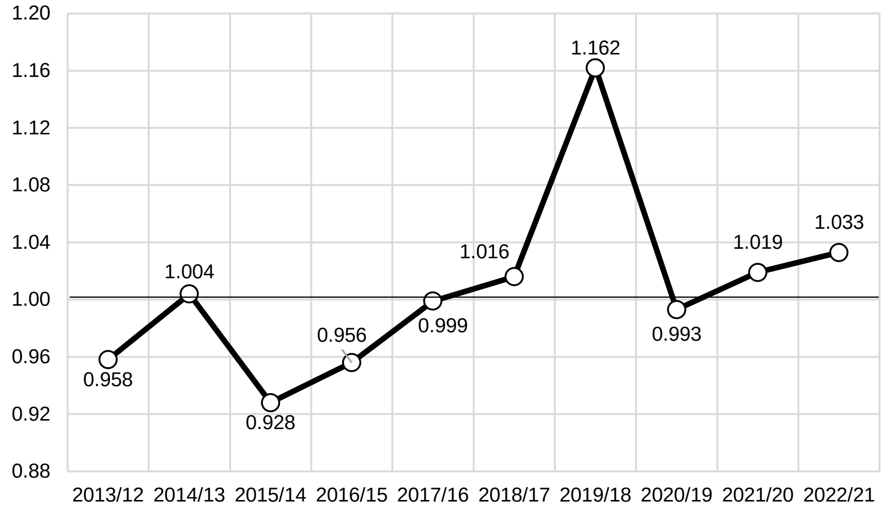
Variant 2 refers to the model with two outputs measured by gross value added and additionally by coverage of imports by exports, while inputs are the same as in variant 1.

The results in the quantitative sense are not the same, as it is expected, but the essential conclusions are the same as in variant 1. There has not been continuity in the growth of total factor productivity in Serbian manufacturing industry as a whole, and there was a maximum of two consecutive years of total factor productivity growth in the observed period.

The highest growth rate was in 2019 which amounted to 16.2%, while the highest decline was in 2015 which amounted to 7.2%.

In Table 4, the structure of total factor productivity changes is shown, and the results are presented for the each year within the observed period, but also as a geometric mean for the entire observed period. According to the mean results in this variant, the total factor productivity has been increasing by a somewhat higher average annual growth rate of 0.5% in the observed period. This is lower growth rate as compared with those obtained in other similar studies, such as that for the Tunisian manufacturing industry whose productivity growth rate was estimated at 2% per year (Zrelli at al., 2020).

Figure 2. Total factor productivity changes in Serbian manufacturing industry, measured by Malmquist indices, 2012-2022 (variant 2)



Source: Authors' calculation

Given the presented structure, the positive changes of productivity have rather been driven by efficiency changes than by technological progress. This difference in the sources of productivity changes, as compared to variant 1, may result from the situation in which manufacturing divisions achieving a significant increase of coverage of imports by exports have been increasing efficiency to a greater extent than adopting technological innovations.

Table 4. Changes in productivity, efficiency and technological progress of Serbian manufacturing industry, measured by Malmquist indices, 2012-2022 (variant 2)

Years	**EFFCH**	**TECHCH**	**PECH**	**SECH**	**TFPCH**
2013/2012	0.838	1.143	0.852	0.984	0.958
2014/2013	1.350	0.744	1.308	1.032	1.004
2015/2014	1.581	0.587	1.492	1.059	0.928
2016/2015	0.809	1.182	0.716	1.130	0.956
2017/2016	2.001	0.499	1.621	1.235	0.999
2018/2017	0.574	1.770	0.812	0.707	1.016
2019/2018	0.816	1.423	0.712	1.147	1.162
2020/2019	1.654	0.600	1.397	1.184	0.993
2021/2020	1.196	0.852	1.240	0.964	1.019
2022/2021	0.943	1.095	0.996	0.947	1.033
MEAN	**1.097**	**0.916**	**1.068**	**1.028**	**1.005**

Source: Authors' calculation

The results by manufacturing divisions of Serbian industry are presented in Table 5. The values for some two-digit division are calculated as a geometric mean of results obtained for every three-digit manufacturing group belonging to that two-digit division. Although Zelenyuk (2006) considered the application of some weighting factors when calculating geometric means, he did not suggest replacement of commonly used equally-weighted components. On the contrary, Pham et al. (2022) emphasize that it is necessary to account for the relative importance of individual decision making units (in our case: manufacturing groups) in the aggregations of indices in general and of the Malmquist productivity index in particular.

All the values indicating changes in productivity, efficiency and technological progress represent the mean for the entire observed period. The manufacturing divisions, marked by appropriate code presented in Table 1, are ranked by the value of total factor productivity change in the last column of the Table 5.

According to the presented results, 14 out of 23 manufacturing divisions are characterized by a positive average annual change of total factor productivity. The best result has been achieved by manufacture of other transport equipment (code 30), considering the average annual growth rate of total factor productivity of 12.5% during the observed period. Manufacture of coke and refined petroleum products (code 19) also achieved a significant average annual growth rate of total factor productivity which amounted to 10.7% during the observed period.

Furthermore, manufacture of electrical equipment (code 27), manufacture of textiles (code 13), and manufacture of non-metallic mineral products (code 23) have achieved an average annual productivity growth rate of more than 5%. Manufacture of beverages (code 11), manufacture of machinery and other equipment (code 28) and manufacture of rubber and plastic products (code 22) can also be singled out with an average annual productivity growth rate higher than 2%. On the other hand, among manufacturing divisions whose productivity declined during the observed period, manufacture of basic metals (code 24) stands out with an average annual productivity growth rate of -16.5%.

Table 5. Changes in productivity, efficiency and technological progress, measured by Malmquist indices, by divisions of Serbian manufacturing industry, 2012-2022 (variant 1)

Code	**EFFCH**	**TECHCH**	**PECH**	**SECH**	**TFPCH**
30	1.102	1.021	1.106	0.997	1.125
19	1.073	1.032	1.072	1.000	1.107
27	1.047	1.027	1.076	0.973	1.075
13	1.029	1.041	1.044	0.986	1.072
23	1.050	1.005	1.049	1.001	1.055
11	1.043	1.005	1.005	1.038	1.047
28	1.011	1.017	1.023	0.988	1.028
22	1.016	1.008	1.012	1.004	1.024
20	1.008	1.007	1.008	1.000	1.015
17	1.013	0.999	1.008	1.005	1.012
12	0.970	1.041	0.956	1.014	1.010
18	1.000	1.007	1.016	0.984	1.007
14	0.988	1.013	1.009	0.979	1.002
25	0.993	1.008	1.001	0.991	1.001
31	0.976	1.011	0.985	0.990	0.987
29	0.967	1.019	0.977	0.989	0.985
16	0.978	1.005	0.990	0.987	0.983
10	0.983	0.997	0.975	1.008	0.980
32	0.972	1.006	0.976	0.996	0.978
26	0.960	1.009	0.962	0.998	0.968
21	0.955	1.001	0.943	1.013	0.956
15	0.943	1.014	0.971	0.971	0.956
24	0.944	0.885	0.962	0.980	0.835

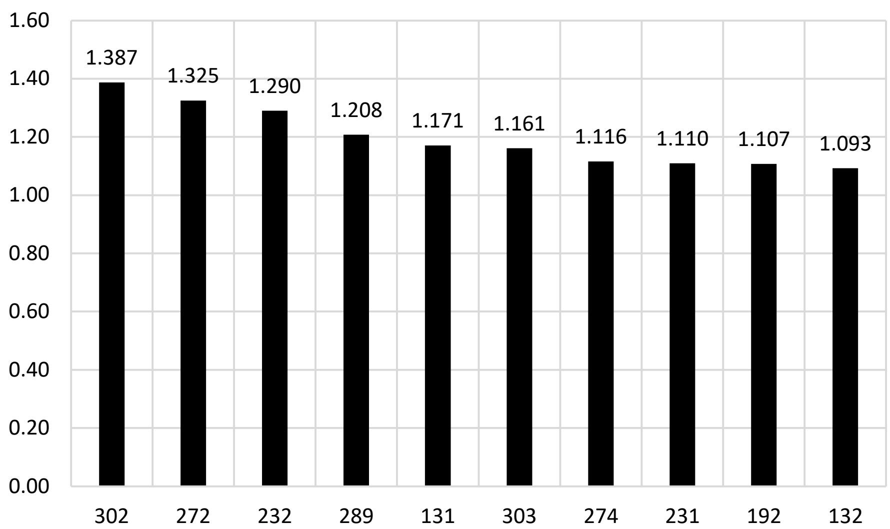
Source: Authors' calculation

Ten most successful three-digit manufacturing groups of Serbian industry by average annual total factor productivity change in the period 2012-2022 are presented in Figure 3. In the vertical axis are the values of the Malmquist index and in the horizontal axis are the three-digit codes of manufacturing groups.

The best result was achieved by manufacture of railway locomotives and rolling stock (code 302), whose productivity increased by the average rate of 38.7% annually. Manufacture of batteries and accumulators (code 272), manufacture of refractory products (code 232), manufacture of other special-purpose machinery (code 289) also achieved the average growth rate of more than 20% annually. Other five best placed groups by average annual growth rate of total factor productivity are as follows: preparation and spinning of textile fibres (code 131), manufacture of air and spacecraft and related machinery (code 303), manufacture of electric lighting equipment (code 274), manufacture of glass and glass products (code 231), manufacture of refined petroleum products (code 192) and weaving of textiles (code 132).

On the other hand, the worst result was achieved in the manufacture of basic iron and steel and of ferro-alloys (code 241). Its total factor productivity has been declining in the observed period by the average rate of 46.4% annually.

Figure 3. Ten most successful manufacturing groups of Serbian industry by average annual total factor productivity change, measured by Malmquist indices, 2012-2022 (variant 1)



Source: Authors' calculation

The results by manufacturing divisions of Serbian industry, in variant 2 with two output measures, are presented in Table 6. The values are calculated in the same way as the values in Table 5. The obtained results are quite similar to those obtained in variant 1. According to the presented results, 16 out of 23 manufacturing divisions are characterized by a positive average annual change of total factor productivity.

Table 6. Changes in productivity, efficiency and technological progress, measured by Malmquist indices, by divisions of Serbian manufacturing industry, 2012-2022 (variant 2)

Code	**EFFCH**	**TECHCH**	**PECH**	**SECH**	**TFPCH**
19	1.073	1.032	1.072	1.000	1.107
27	1.139	0.921	1.124	1.013	1.049
11	1.043	1.005	1.005	1.038	1.047
22	1.088	0.956	1.011	1.076	1.040
13	1.054	0.978	1.041	1.013	1.031
30	1.153	0.894	1.188	0.970	1.030
14	1.098	0.932	1.031	1.065	1.023
25	1.132	0.903	1.069	1.058	1.023
21	1.117	0.913	1.068	1.045	1.019
26	1.098	0.925	1.093	1.004	1.016
29	1.069	0.946	1.054	1.014	1.011
12	0.970	1.041	0.956	1.014	1.010
10	1.069	0.944	0.988	1.083	1.009
16	1.085	0.929	1.065	1.019	1.008
18	1.000	1.007	1.016	0.984	1.007
17	1.046	0.956	1.030	1.015	1.001
23	1.096	0.910	1.080	1.015	0.998
20	1.067	0.930	1.030	1.035	0.991
28	1.054	0.938	1.055	1.000	0.989
31	0.976	1.011	0.985	0.990	0.987
15	1.064	0.922	1.037	1.027	0.981
32	1.214	0.805	1.232	0.986	0.978
24	1.057	0.849	1.009	1.047	0.897

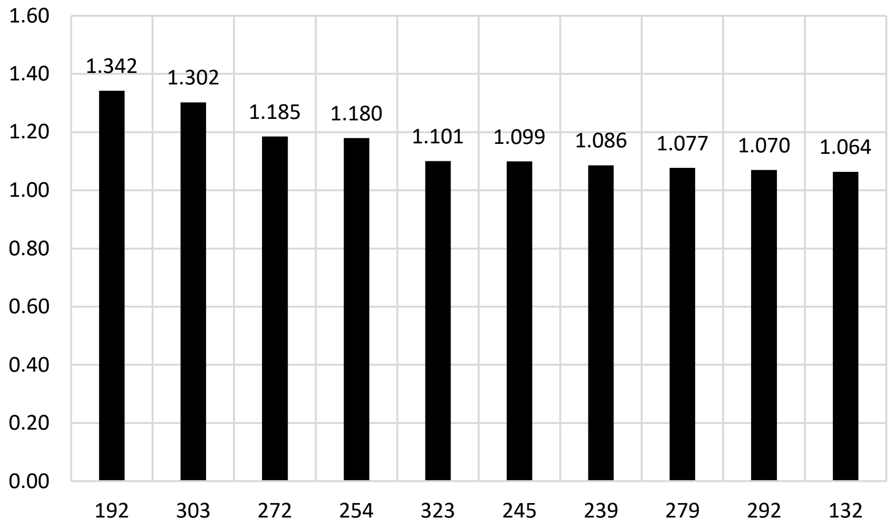
Source: Authors' calculation

The best result has been achieved by manufacture of coke and refined petroleum products (code 19), considering the average annual growth rate of total factor productivity of 10.7% during the observed period. The average annual productivity growth rates between 3% and 5% were achieved within manufacture of electrical equipment (code 27), manufacture of beverages (code 11), manufacture of rubber and plastic products (code 22), manufacture of textiles (code 13) and manufacture of other transport equipment (code 30).

Furthermore, manufacture of wearing apparel (code 14) and manufacture of fabricated metal products, except machinery and equipment (code 25) have achieved an average annual productivity growth rate of more than 2%. On the other hand, among manufacturing divisions whose productivity declined during the observed period, manufacture of basic metals (code 24) stands out with an average annual productivity growth rate of -10.3%, which is quite similar as in variant 1.

Ten most successful three-digit manufacturing groups of Serbian industry by average annual total factor productivity change in the period 2012-2022, in variant 2 with two output measures, are presented in Figure 4. In the vertical axis are the values of the Malmquist index and in the horizontal axis are the three-digit codes of manufacturing groups.

Figure 4. Ten most successful manufacturing groups of Serbian industry by average annual total factor productivity change, measured by Malmquist indices, 2012-2022 (variant 2)



Source: Authors' calculation

According to the results from variant 2, the best result was achieved by manufacture of refined petroleum products (code 192), whose productivity increased by the average rate of 34.2% annually. Manufacture of air and spacecraft and related machinery (code 303), manufacture of batteries and accumulators (code 272), and manufacture of weapons and ammunition (code 254) also achieved the average growth rate of more than 18% annually. Other six best placed groups by average annual growth rate of total factor productivity are as follows: manufacture of sports goods (code 323), casting of metals (code 245), manufacture of abrasive products and non-metallic mineral products (code 239), manufacture of other electrical equipment (code 279), manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers (code 292) and weaving of textiles (code 132).

On the other hand, the worst result was achieved in the manufacture of basic iron and steel and of ferro-alloys (code 241), which confirms the results from variant 1. The total factor productivity of this manufacturing group has been declining in the observed period by the average rate of 39.1% annually.

Considering the most important obtained results, especially a low average annual growth rate of productivity, it has to be emphasized that there are some empirical findings which suggest the Malmquist productivity index could underestimate productivity growth. Therefore, Yörük & Zaim (2005) proposed the application of an alternative Malmquist-Luenberger productivity index, which could be done in some further research. Moreover, the next step could be directed toward the forecasting of the Malmquist productivity indices, as described by Daskovska et al. (2010).

4. Conclusion

Industrial production takes place in a very complex and dynamic, both domestic and global, macroeconomic and political environment. By applying the Malmquist productivity indices calculated by DEA program, the paper contributes to better understanding of trends in development of Serbian manufacturing industry during the period 2012-2022.

The total factor productivity of the manufacturing industry as a whole has been increasing by a low average annual growth rate of around 0.5%. The manufacturing industry lacks the continuity of growth which would last for more than two years consecutively. Two thirds of manufacturing divisions are characterized by productivity growth, while the remaining one third did not succeed to achieve positive productivity change. The most successful divisions include the manufacture of coke and refined petroleum products, electrical equipment and other transport equipment. Sources for their productivity growth could be found rather in efficiency improvements at existing technological level, than in innovations and technological changes. On the other hand, the most unfavorable results are related to the manufacture of basic metals, especially iron and steel. The total factor productivity in those manufacturing groups has been declining by a double digit average annual growth rate.

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