Formosa Journal of Multidisciplinary Research (FJMR)
Vol. 4, No. 5, 2025: 2001-2014

Analysis of Total Factor Productivity in Indonesia's Large and Medium-Scale Industries in Response to Industry 4.0

Farhan Habibie[1], Rizalul Kalam[2*]
[1]Fakultas Ekonomi dan Bisnis, Universitas Padjadjaran, Indonesia
[2]Institut Sains dan Teknologi Nasional, Indonesia
Corresponding Author: Rizalul Kalam rizalulkalam1@gmail.com

A R T I C L E I N F O
Keywords: Total Factor Productivity, Industry 4.0, Stochastic Frontier Analysis, Technological Change

Received : 12, April
Revised : 26, April
Accepted: 14, May

A B S T R A C T
This study examines the impact of Industry 4.0 on Total Factor Productivity (TFP) in Indonesia's large and medium-scale industries from 2010 to 2015. Utilizing the Stochastic Frontier Analysis (SFA) method with a translog production function, the research analyzes the relationship between inputs (capital, labor, and raw materials) and industrial output, while decomposing TFP growth into efficiency changes (EC), technological changes (TC), and scale effects (SC). The findings reveal that labor and raw materials significantly influence output, with labor exhibiting the highest elasticity (0.6389). The average TFP growth rate was 3.689%, primarily driven by technological advancements (6.996%), despite a decline in technical efficiency (-3.358%). The motor vehicle and food industries demonstrated the highest technical efficiency, while sectors like wood and furniture lagged. The study highlights Indonesia's reliance on foreign technology and underscores the need for domestic innovation to enhance Industry 4.0 readiness. Policy recommendations include fostering R&D collaboration and improving infrastructure to sustain productivity growth.

DOI: https://doi.org/10.55927/fjmr.v4i5.173
ISSN-E: 2829-8896
https://npaformosapublisher.org/index.php/fjmr

INTRODUCTION

Globalization and technology are driving a new wave of revolution in the industrial world. Currently, the world is entering the era of the fourth industrial revolution or commonly known as industry 4.0. According to Angreani et al., (2020), industry 4.0 is a phase involving the integration of technology such as Cyber Physical System (CPS) into manufacturing and logistics processes. Similar statements are found in research Goel & Noida (2021), which states that in the fourth industrial revolution, the role of technology is very necessary and is expected to drive the rate of economic growth, especially for Indonesia as a developing country. Agarwal et al. (2017) stated that industry 4.0 can be an opportunity for the processing industry to increase productivity so that it can significantly improve performance. Solomon & Van Klyton (2020) stated in his research that the use of technology in companies can increase productivity for workers so that it can encourage efficiency in production. In other research Li et al. (2020) also stated the same relationship that the application of digital technology can facilitate the process of producing goods and services, of course this can have a positive impact on the economic performance of a country.

Furthermore, Baneliene (2021) stated that a country that is advanced in the manufacturing industry sector will have high added value so that it has a higher impact on a country's Gross Domestic Product (GDP). Therefore, developing countries should pay more attention to the growth of the manufacturing industry sector. The manufacturing industry sector certainly has an important role as a supporter of national economic growth. Based on statistical data (Central Bureau of Statistics, 2020), it is known that the contribution of the manufacturing sector to Indonesia's GDP in 2016 was 20.52%, then dropped to 20.16% in 2017, then to 19.7% and 19.86% for 2019 and 2020 respectively. This does show that the manufacturing sector has the highest contribution to Indonesia's GDP compared to other sectors.

However, the contribution from the manufacturing industry sector tends to decline from year to year. This is in line with research Surjaningsih & Permono (2014) which examines the productivity of large and medium industries in Indonesia, where the productivity of large and medium industries shows a downward trend which is confirmed by the contribution figures of the manufacturing industry sector to GDP in Indonesia. Pratiwi et al. (2010) which examines the productivity of the processing industry in Bali also shows a similar pattern. This certainly needs to be known how efficient the performance of the processing industry is towards its output.

Seker & Saliola (2018) states that Total Factor Productivity (TFP) is known as a tool to measure how efficient the input used for its product. Its value shows that the higher the TFP value, the more efficient the input allocated in producing output. Shen et al. (2020) states that TFP is one of the indices in measuring the level of quality of economic development. In addition to efficiency in TFP, TFP growth is also important to note. TFP growth is growth in productivity, in which growth, the output that grows does not come from production input. TFP growth is also a reflection of technological progress and improvements in efficiency (Jia et al., 2020). The method for estimating TFP growth is summarized in the research

Margono & Sharma (2006) is by means of neo-classical approach, decomposition approach and also growth-accounting approach. In the decomposition approach, TFP growth is divided into three factors, namely technology factor, economy scale factor and technical efficiency change factor.

This study is based on global conditions where the world including Indonesia is entering the era of industry 4.0, where through industry 4.0 it is expected that there will be an increase in productivity. Therefore, it is necessary to further examine the productivity conditions of the processing industry sector, especially large and medium industries, in the early era of industry 4.0. This study will analyze the relationship between input from a production factor such as capital and labor to the output produced by large and medium industries in Indonesia, to further analyze the TFP growth rate. For further analysis, a TFP decomposition approach will be used to determine what causes the movement of TFP between years. The results of this analysis will be a picture of the readiness of large and medium industries in Indonesia in facing industry 4.0.

A similar study was conducted by Eskani (2010) which examines the total TFP growth with fixed effect analysis in large and medium industries where the results show that the average TFP of the large and medium industrial sector is 1.39 times its input, while its growth is at 1.83% in 2001-2005. Other research related to the TFP of the large and medium industrial sector has also been conducted by Surjaningsih & Permono (2014), with results showing that in the period 2000-2009 the aggregate TFP growth was 7.44% per year with the largest source being technological change, but there was a decline in changes in technical efficiency.

LITERATURE REVIEW

Concept of Production and Productivity

Production is a process of converting input into output (Ayu Puspitasari, 2017), while productivity is the ability to produce an output from the use of certain inputs. This statement is supported by research (de la Fuente-Mella et al., 2020) which also states that productivity is the level of efficiency of resource use such as capital and labor in producing a certain output. Therefore, the level of productivity and efficiency are important indicators to see whether an industry has good performance or not.

Surjaningsih & Permono (2014) state that efficiency can be measured with three options, namely input oriented, output oriented and distance function. In input oriented, efficiency is measured by determining a certain amount of output using the most minimal input. While in output oriented, the amount of input is determined in order to achieve the maximum possible output.

Production Function

The production function is the relationship between an input of goods and its output and the production function shows the influence of an input on the output of a production (Mankiw, 2018). In studies on production efficiency, the production function is often used as the basis of a research model, such as in research Eskani (2010), Pratiwi et al. (2010) Andde la Fuente-Mella et al. (2020).

Referring to Mankiw (2018), the following is the equation of the production function:

$$Y = AF(K, L) \quad (1)$$

Information:

Y =$Output$

A = Technology advances

K = Capital

L = Labor

There are several studies that have discussed TFP and efficiency, especially in the processing industry both in Indonesia and other countries. One of them is in the research conductedde la Fuente-Mella et al. (2020) which examined the efficiency of the processing industry in Chile in 1995-2010. The results of the study showed that technical efficiency in the processing industry sector was at the level of 32%-63%, but experienced a decline in efficiency every year in the entire industry. The results of the study also showed that the chemical industry sector and the food and beverage industry sector were the sectors with the highest efficiency. Margono & Sharma (2006) also examined the technical efficiency of the processing industry in Indonesia with results showing that the average technical efficiency of the processing industry in Indonesia in 1993-2000 was at the level of 46%-68%.

In the study related to TFP growth, the research conducted Ikhsan (2007) shows that the average growth of TFP of the manufacturing industry in Indonesia in 1988-2000 was 1.55%, where technological change contributed greatly to TFP growth. Research on TFP of the manufacturing industry in Indonesia in 2001-2005 conducted by Eskani (2010) shows that the average TFP growth is 1.83%. For other country studies written by Mahadevan (2002) With Data Envelopment Analysis (DEA), the manufacturing industry in Malaysia from 1981-1996 experienced an average TFP growth of 0.8% per year.

METHODOLOGY

Data and Variables

The data to be used in this study is secondary data obtained from the Central Statistics Agency (BPS) which is then processed. The data used is data on Large and Medium Industries in Indonesia based on the Indonesian Standard Industrial Classification (KBLI) in 2010-2015. The variables in this study are variables based on current prices (nominal data) which will then be deflated with a certain deflator based on data from the Central Statistics Agency (BPS). The variables and deflators used in this study can be seen in Table 1.

Table 1. Variable Data and Deflators Used

Data	Unit	Deflator used in this study	Deflator used in the study (Surjaningsih & Permono, 2014)
Output Value	In billions of rupiah	IHPB Industry	IHPB based on industry type
Estimated Value of All Fixed Capital Goods	In billions of rupiah	PMTB based on GDP by expenditure	PMTB
Cost of Raw Materials and Auxiliaries	In billions of rupiah	IHPB General	Total IHPB
Labor	Number of people	-	-

Source: Processed data

To measure TFP growth, according to Coelli, TJ, Rao, DSP, & Battese (2005) the analysis technique that can be used is the Data Envelopment Analysis (DEA) approach or the Stochastic Frontier Analysis (SFA). The DEA approach does not consider the existence of random errors, as a result, calculations with DEA can be biased when the production process is more characterized by the presence of stochastic elements. In this study, the method used is the stochastic frontier analysis approach with the translog production function model whose equation refers to Coelli, TJ, Rao, DSP, & Battese, (2005), as follows:

$$\ln O_{it} = \beta_0 + \beta_t t + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \beta_M \ln M_{it} + \frac{1}{2}\beta_{tt}(t)^2 + \beta_{tK} t.\ln K_{it} + \beta_{tL} t.\ln L_{it} + \beta_{tM} t.\ln M_{it} + \frac{1}{2}\beta_{KK}(\ln K_{it})^2 + \beta_{KL}\ln K_{it}\ln L_{it} + \beta_{KM}\ln K_{it}\ln M_{it} + \frac{1}{2}\beta_{LL}(\ln L_{it})^2 + \beta_{LM}\ln L_{it}\ln M_{it} + \frac{1}{2}\beta_{MM}(\ln M_{it})^2 + v_{it} - u_{it} \quad (2)$$

Information:
$O_{it} = Output\ value$
$K_{it} = Capital\ value$
$L_{it} = Number\ of\ workers$
$M_{it} = Raw\ material\ value$
$i = Sector\ to\ 1, 2, \dots, i$
$t = Year\ to\ 1, 2, \dots, t$

In calculating Total Factor Productivity Growth (TFPG), the calculation process uses an equation that refers toKumbhakar & Lovell (2012). TFPG can be decomposed into efficiency changes (EC), technological changes (TC), and also changes in economies of scale (SC) where each calculation can be formulated into the following equation:

$$EC = -\frac{\partial u}{\partial t} \quad (3)$$

$$SC = (\varepsilon - 1) \cdot \sum_n \left(\frac{\varepsilon_n}{\varepsilon}\right) \dot{\chi}_n \quad (5)$$

$$TC = \frac{\partial \ln O_{it}}{\partial t} \quad (4) \qquad \varepsilon = \sum_{n} \varepsilon_n \quad (6)$$

Information:
$u = Technical\ Efficiency$
ε_n = Elasticity of inputs (capital, raw materials, labor)
$\dot{\chi_n}$ = Growth rate of inputs (capital, raw materials, labor)

Technological change (TC) in equation (4) and input elasticity (εn) in equation (6), can also be written as the following equation:

$$TC = \frac{\partial \ln O_{it}}{\partial t} = \beta_t + \beta_{tt} t + \beta_{Kt} \ln K_{it} + \beta_{Lt} \ln L_{it} + \beta_{Mt} \ln M_{it} \quad (7)$$

$$\varepsilon_n = \frac{\partial \ln O_{it}}{\partial n} = \beta_n + \beta_{nt} t + \beta_{nK} \ln K_{it} + \beta_{nL} \ln L_{it} + \beta_{nM} \ln M_{it} \quad (8)$$

Based on the calculations above, it can be seen that TFPG is as follows:

$$TFPG = -\frac{\partial u}{\partial t} + \frac{\partial \ln O_{it}}{\partial t} + (\varepsilon - 1) \cdot \sum_{n} \left(\frac{\varepsilon_n}{\varepsilon}\right) \dot{\chi_n} \quad (9)$$

$$TFPG = EC + TC + SC \quad (10)$$

RESEARCH RESULT AND DISCUSSION

Based on the estimation results of Large and Medium Industries (IBS) data in Indonesia in 2010-2015 using the Stochastic Frontier Analysis (SFA) method as shown in Table 2, it can be seen that the main variables such as the number of workers and raw materials have a significant effect on output with a t-ratio value greater than the t-table value of 2.576 (α = 1%). The capital variable also has a significant effect at α = 5% on the output value of large and medium industries in Indonesia, this is shown in the t-ratio value which is greater than the t-table value of 1.96 (α = 5%).

Variables such as labor and raw materials have a positive influence on output production, this shows that in order to maximize industrial output production, it can be done through increasing raw materials and labor. In this model, the time variable also has an influence on output with a coefficient of 0.05, which means that an increase in time of one year provides an increase in output of 5%, ceteris paribus. However, the t-ratio value <t table (α = 5%) shows that the time variable does not have a significant influence on the output value. Coelli, TJ, Rao, DSP, & Battese, (2005) explains that gamma (γ) shows the variation in the error term caused by the inefficiency factor. In this study, the gamma (γ) parameter is 0.90 and is significant at α = 1% indicating that 90% of the variation in the error term is caused by the inefficiency factor.

Table 2. Estimation Results Using Stochastic Frontier in Large and Medium Industries in Indonesia 2010-2015

Variables	Parameter	Coefficient	*Standard Error*	*t-ratio*
Constants	β0	-4.53688**	1.01270	-4.47999
t	β1	0.05078	0.07047	0.72067
lnK	β2	-0.16851*	0.07795	-2.16186
lnL	β3	1.34814**	0.30377	4.43803
lnM	β4	0.91073**	0.28637	3.18022
t2	β5	0.00461	0.00440	1.04762
t(lnK)	β6	0.00991	0.00698	1.41909
t(lnL)	β7	0.01839*	0.00933	1.97210
t(lnM)	β8	-0.03186**	0.00943	-3.37698
lnK2	β9	-0.00340	0.00311	-1.09435
lnK(lnL)	β10	0.01273	0.01198	1.06292
lnK(lnM)	β11	0.00776	0.01503	0.51646
lnL2	β12	-0.03994	0.02671	-1.49537
lnL(lnM)	β13	-0.04339	0.04301	-1.00872
lnM2	β14	0.01355	0.02439	0.55545
	sigma-squared (σ2)	0.11415**	0.02387	4.78262
	gamma (γ)	0.90146**	0.02026	44.48637
	mu (μ)	0.64156	0.12498	5.13337
	this (η)	-0.05723	0.02792	-2.05025

*Note: **): significant at a=1%; *): significant at a=5%*
Source: Processed data

Table 3. Average Highest Efficiency Level Based on Industrial Sector in 2010-2015

Description of KBLI	KBLI Code	Technical Efficiency
Motor Vehicle, Trailer and Semi Trailer Industry	29	0.9550
Food Industry	10	0.7305
Non-Metallic Mining Industry	23	0.7303
Tobacco Processing Industry	12	0.7044
Other Transportation Industry	30	0.6987
Chemical and Chemical Products Industry	20	0.6981
Electrical Equipment Industry	27	0.6720
Machinery and Equipment Industry Ytdl	28	0.6386
Basic Metal Industry	24	0.6000
Paper and Paper Products Industry	17	0.5628
Beverage Industry	11	0.5534
Coal and Petroleum Refining Products Industry	19	0.5374
Rubber Industry, Rubber and Plastic Goods	22	0.5373
Textile Industry	13	0.5253
Pharmaceutical Industry, Chemical Drug Products and Traditional Medicines	21	0.5249
Computer, Electronic and Optical Industry	26	0.5178

Ready-to-wear Apparel Industry	14	0.5043
Machine and Equipment Repair and Installation Services	33	0.4986
Metal Goods Industry, Not Machinery and Equipment	25	0.4723
Leather Industry, Leather Goods and Footwear	15	0.4405
Printing and Reproduction Industry of Recorded Media	18	0.4239
Wood Industry, Wood and Cork Products (Excluding Furniture) and Woven Products from Bamboo, Rattan and the Like	16	0.3791
Furniture Industry	31	0.3505
Other Processing Industries	32	0.3403

Source: processed data

Coelli, TJ, Rao, DSP, & Battese (2005) states that the level of technical efficiency measurement is measured based on a value from 0 to 1. A value of 0 indicates that a company is inefficient in carrying out production activities while a value of 1 represents that the company is efficient in allocating input. Based on Table 3, the level of technical efficiency in the industrial sector is at the level of 34% to 95%. When viewed based on the industrial sector, the industry with the highest technical efficiency is the motor vehicle industry (KBLI 29) with a technical efficiency level of 0.95. The second highest sector is the food industry sector (KBLI 10) with a technical efficiency level of 0.73. The same thing was found in research in Chile (de la Fuente-Mella et al., 2020) which shows that the food industry sector is one of the industrial sectors with the highest level of technical efficiency, and this confirms that the food industry in developing countries is relatively more efficient and plays a significant role in the economy. Meanwhile, the industrial sector with the lowest technical efficiency value comes from the wood industry, furniture industry and other processing industries with a technical efficiency level below 0.4.

Table 4. Input Elasticity in Large and Medium Industries in Indonesia

Year	εk	εl	εm	ε
2010	0.0347	0.5892	0.5836	1.2075
2011	0.0441	0.6095	0.5530	1.2066
2012	0.0540	0.6279	0.5214	1.2034
2013	0.0653	0.6412	0.4865	1.1929
2014	0.0687	0.6850	0.4670	1.2207
2015	0.0844	0.6807	0.4247	1.1897
Average	0.0585	0.6389	0.5060	1.2035

Source: processed data

Based on the input elasticity calculated based on equation (8), it can be seen in Table 4 that labor has the highest average elasticity of 0.6389, which means that every 1% increase in the number of workers will increase output by 0.6389%. In addition, it can be concluded that the use of labor has a higher influence on the output of large and medium industries in Indonesia compared to other inputs such as capital and raw materials, this can be seen from the elasticity of labor to output which tends to increase every year from 0.5892 in

2010 to 0.6807 in 2015. In raw material input, the average elasticity of 0.5060 indicates that every 1% increase in the use of raw materials will increase the amount of output by 0.5%. Capital is an input that has the smallest elasticity compared to the others, with an average of 0.0585. However, in capital, its elasticity begins to increase every year, this indicates that the use of capital begins to have a greater influence on its output. Low elasticity of capital is also shown in studies conducted Ikhsan (2007) regarding the processing industry in Indonesia in 1988-2000 and in the study conducted Pratiwi et al. (2010) regarding large and medium industries in Bali in 2001-2010.

Table 5. Average TFP Growth by Year

Year	*Eff. Change*	*Tech. Change*	*Scale Change*	TFPG
2011	-2.993%	5.565%	0.068%	2.641%
2012	-3.166%	6.261%	0.086%	3.180%
2013	-3.348%	6.433%	0.002%	3.087%
2014	-3,540%	8.991%	0.183%	5.634%
2015	-3.744%	7.729%	-0.084%	3.902%
Average	-3.358%	6.996%	0.051%	3.689%

Source: Processed data

Table 6. Average TFP Growth by Industrial Subsector

KBLI	Sector	SC	E.C.	TC	TFP
23	Non-Metallic Mining Industry	0.05%	-1.78%	8.64%	6.91%
14	Ready-to-wear Industry	0.04%	-3.84%	10.70%	6.89%
33	Machine and Equipment Repair and Installation Services	0.08%	-3.91%	10.31%	6.48%
11	Beverage Industry	0.06%	-3.33%	8.90%	5.63%
21	Pharmaceutical Industry, Chemical Drug Products and Traditional Medicines	0.06%	-3.62%	8.86%	5.30%
15	Leather Industry, Leather Goods and Footwear	0.04%	-4.59%	9.24%	4.70%
29	Motor Vehicle, Trailer and Semi Trailer Industry	0.05%	-0.26%	4.60%	4.39%
28	Machinery and Equipment Industry Ytdl	0.06%	-2.53%	6.68%	4.21%
31	Furniture Industry	0.05%	-5.84%	9.83%	4.04%
12	Tobacco Processing Industry	0.04%	-1.98%	5.86%	3.92%
20	Chemical Industry and Chemical Products	0.05%	-2.03%	5.68%	3.70%
30	Other Transportation Equipment Industry	0.06%	-2.03%	5.67%	3.70%
32	Other Processing Industries	0.05%	-6.00%	9.53%	3.58%
16	Wood Industry, Wood and Cork Products (Excluding Furniture) and Woven Products from Bamboo, Rattan and the Like	0.04%	-5.41%	8.54%	3.18%
13	Textile Industry	0.03%	-3.62%	6.74%	3.15%
27	Electrical Equipment Industry	0.05%	-2.25%	5.15%	2.96%
25	Metal Goods Industry, Not Machinery and Equipment	0.05%	-4.21%	7.05%	2.90%
26	Computer, Electronic and Optical Industry	0.05%	-3.70%	6.45%	2.80%
18	Printing and Reproduction Industry of Recorded Media	0.06%	-4.80%	7.44%	2.70%
10	Food Industry	0.03%	-1.78%	4.32%	2.58%

22	Rubber Industry, Rubber and Plastic Goods	0.04%	-3.49%	5.47%	2.02%
17	Paper and Paper Products Industry	0.05%	-3.24%	4.48%	1.30%
19	Coal and Petroleum Refining Products Industry	0.08%	-3.49%	4.56%	1.15%
24	Basic Metal Industry	0.06%	-2.88%	3.18%	0.36%

Source: Processed data

Based on the TFP growth (Table 5) calculated from equation (9), it can be seen that the efficiency change factor has decreased every year with an average decrease of 3.358%. This tendency for decreasing efficiency changes is also found in research. Ikhsan (2007) And Pratiwi et al. (2010). The decreasing rate of efficiency change indicates that each input used can actually still be maximized to produce higher output. Meanwhile, the contribution of changes in economic scale to TFPG shows a fluctuating rate with an average of 0.051% per year.

When viewed based on industrial subsectors (Table 6), the non-metallic mining industry subsector is the subsector with the highest TFP growth of 6.91% followed by the apparel industry subsector which is the second highest subsector with TFP growth of 6.89%. Furthermore, based on the contribution of technological change, the apparel industry subsector (KBLI 14) is also the sector with the highest contribution to TFP growth at 10.70%, followed by machine repair and installation services (KBLI 33) with TFP growth originating from technological change of 10.31%.

In the technological change factor, it can be seen that technology provides the largest contribution to TFP growth with an average of 6.996%. This shows that in facing industry 4.0, large and medium industries in Indonesia have been accompanied by technological developments that lead to increased productivity and of course can support the implementation of industrial technology 4.0. This is coupled with the rate of technological change which tends to increase every year even though it decreased in 2015 which was originally in 2014 by 8.991% to 7.73% in 2015.

However, if we look deeper, the increase in technology in Indonesia still seems to come from abroad. Based on the mapping of the World Economic Forum (WEF) in 2018 regarding the readiness of countries to produce or compete in the future era, it can be seen that Indonesia's technology and innovation score is at 4.0 (scale 0 to 10). Several assessments that caused the low score are factors such as R&D expenditures, patent applications and scientific publications (Antara et al. 2019a). While the score or value of the technology transfer factor and firm level technology absorption is relatively better. This is certainly an opportunity and challenge for the government in improving the improvement and development of technology including improving its infrastructure.

In 2019, the Indonesian Government launched the Indonesia Industry 4.0 Readiness Index (INDI 4.0). INDI 4.0 is an indicator for assessing the level of industrial readiness in Indonesia in implementing technology in the era of industry 4.0. The assessment includes five pillars starting from management and organization, people and culture, products and services, technology, and factory operations. The INDI 4.0 assessment score range consists of five levels, namely level zero which means not ready to transform to industry 4.0. Level one, the industry is still at the initial readiness stage. Furthermore, level two, namely the industry is at the moderate readiness stage, level three, the industry is at the stage of mature readiness to transform to industry 4.0, and level four, namely the industry has implemented most of the concepts of industry 4.0 in its production system (Antara et al. 2019b). As of 2020, 706 companies have participated in the INDI 4.0 assessment with the results that 0.5% of the industry is at level four, then 16.5% is at level three, 44.6% of the industry is at level two, 33% is at level one and the rest is at level zero (Ministry of Industry, 2020). To be able to improve the readiness of the industry that requires a leap in efficiency and productivity through industrial technology 4.0, this is a challenge for stakeholders and industrial managers in formulating policies, programs and incentives that are attractive to the industry so that they can participate in the transformation.

Technology development should come from two sides, in addition to foreign sources in the form of Foreign Direct Investment (FDI) and technology transfer, increasing the supply side of technology from within the country is important. To grow this, Making Indonesia 4.0 has set it in the national priority program, namely the development of an innovation ecosystem. Several government programs, namely the development of a national innovation center roadmap, preparing pilot innovation centers and optimizing related regulations, including the protection of intellectual property rights and fiscal incentives to accelerate cross-sector collaboration between private business actors/state owned company with universities must continue to be encouraged, monitored and evaluated. This is so that the momentum of implementing industry 4.0 is not just a slogan with imported technology alone, but can also increase the added value of the industry through increasing inclusive domestic technology involving all stakeholders.

CONCLUSIONS AND RECOMMENDATIONS

This study highlights the critical role of technological advancements in driving Total Factor Productivity (TFP) growth in Indonesia's large and medium-scale industries during the early Industry 4.0 era. While labor and raw materials significantly boost output, declining technical efficiency underscores inefficiencies in resource allocation. The motor vehicle and food industries emerge as top performers, whereas sectors like wood and furniture lag behind. Indonesia’s reliance on foreign technology signals the need for stronger domestic innovation and R&D investment. Policymakers must prioritize infrastructure development, foster industry-academia collaboration, and incentivize technology adoption to enhance productivity and global competitiveness. Addressing these challenges will be vital for sustainable industrial growth in the digital economy.

ADVANCED RESEARCH

Further studies should investigate sector-specific adoption patterns of Industry 4.0 technologies in Indonesian manufacturing, assessing their differential impacts on productivity. Research could examine how institutional frameworks and workforce readiness moderate these effects, employing mixed-methods approaches. Comparative analyses with regional peers would contextualize Indonesia's industrial transformation.

REFERENCES

Agarwal, B. V., Lath, V., & Mancini, M. (2017). Confronting Indonesia's Productivity Challenge. *McKinsey & Company*.

Angreani, L. S., Vijaya, A., & Wicaksono, H. (2020). Systematic Literature Review of Industry 4.0 Maturity Model for Manufacturing and Logistics Sectors. *Procedia Manufacturing*, *52*(2019), 337–343. https://doi.org/10.1016/j.promfg.2020.11.056

Antara, N. T. et all. (2019a). *Making Indonesia 4.0: Transformasi Industri Manufaktur Nasional ke Industri 4.0* (D. Prabantini (ed.); I). Penerbit ANDI.

Antara, N. T. et all. (2019b). *Perjalanan Indonesia Menyongsong Revolusi Industri Keempat*. BPPI.

Ayu Puspitasari, I. (2017). Analisis Efisiensi Industri Rokok di Indonesia dengan Menggunakan Metode Data Envelopment Analysis Tahun 2006 - 2008. *Media Ekonomi; Vol 19, No 2 (2011)DO - 10.25105/Me.V19i2.830*.

Badan Pusat Statistik. (2020). PDB Indonesia Triwulanan 2016-2020. *07130.2002*, 98.

Banelienė, R. (2021). Industry impact on GDP growth in developed countries under R&D investment conditions. *Journal of Small Business Strategy*, *31*(1), 66–80.

Battese, G. E. C. T. J. R. D. S. P. (2005). An introduction to efficiency and productivity analysis. In *An Introduction to Efficiency and Productivity Analysis*. https://doi.org/10.1007/b136381

de la Fuente-Mella, H., Rojas Fuentes, J. L., & Leiva, V. (2020). Econometric modeling of productivity and technical efficiency in the Chilean manufacturing industry. *Computers and Industrial Engineering*, *139*(xxxx), 105793. https://doi.org/10.1016/j.cie.2019.04.006

Eskani, I. N. (2010). Total Factor Productivity (TFP) Industri Menengah Dan Besar Di Indonesia. *Dinamika Kerajinan Dan Batik*, *28*, 17–24. https://doi.org/10.22322/dkb.v28i1.1133

Goel, H., & Noida, G. (2021). Exploring the Architecture of Fourth Industrial Revolution : Globalization 4 . 0. *FOCUS: Journal of International Business*, *December 2020*. https://doi.org/10.17492/jpi.focus.v7i2.722008

Ikhsan, M. (2007). Total Factor Productivity Growth in Indonesian Manufacturing: A Stochastic Frontier Approach. *Global Economic Review*, *36*(4), 321–342. https://doi.org/10.1080/12265080701694488

Jia, F., Ma, X., Xu, X., & Xie, L. (2020). The differential role of manufacturing and non-manufacturing TFP growth in economic growth. *Structural Change and Economic Dynamics*, *52*, 174–183. https://doi.org/10.1016/j.strueco.2019.10.006

Kementerian Perindustrian. (2020). *Laporan Jumpa Pers Akhir Tahun 2020*.

Kumbhakar, S. C., & Lovell, C. A. K. (2012). The Estimation of Efficiency Change and Productivity Change. In *Stochastic Frontier Analysis*. https://doi.org/10.1017/cbo9781139174411.009

Li, Y., Dai, J., & Cui, L. (2020). The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. *International Journal of Production Economics*, *229*(March), 107777. https://doi.org/10.1016/j.ijpe.2020.107777

Mahadevan, R. (2002). A DEA approach to understanding the productivity growth of Malaysia's manufacturing industries. *Asia Pacific Journal of Management*, *19*(4), 587–600. https://doi.org/10.1023/A:1020577811369

Mankiw, N. G. (2018). *Principles of economics*.

Margono, H., & Sharma, S. C. (2006). Efficiency and productivity analyses of Indonesian manufacturing industries. *Journal of Asian Economics*, *17*(6), 979–995. https://doi.org/10.1016/j.asieco.2006.09.004

Pratiwi, A. M., Bendesa, I. K. G., & Yuliarmi, N. (2010). Analisis Efisiensi dan Produktivitas Industri Besar dan Sedang di Wilayah Provinsi Bali (Pendekatan Stochastic Frontier Analysis). *Jurnal Ekonomi Kuantitatif Terapan*.

Şeker, M., & Saliola, F. (2018). A cross-country analysis of total factor productivity using micro-level data. *Central Bank Review*, *18*(1), 13–27. https://doi.org/10.1016/j.cbrev.2018.01.001

Shen, Y., Yue, S., Sun, S., & Guo, M. (2020). Sustainable total factor productivity growth: The case of China. *Journal of Cleaner Production*, *256*, 120727. https://doi.org/10.1016/j.jclepro.2020.120727

Solomon, E. M., & Van Klyton, A. (2020). The impact of digital technology usage on economic growth in Africa. *Utilities Policy*, *67*(July), 101104. https://doi.org/10.1016/j.jup.2020.101104

Surjaningsih, N., & Permono, B. P. (2014). Dinamika Total Factor Productivity Industri Besar Dan Sedang Indonesia. *Buletin Ekonomi Moneter Dan Perbankan*, *16*(3), 277–308. https://doi.org/10.21098/bemp.v16i3.46