Trends of Total Factor Productivity of G7's Manufacturing Sector

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Abstract:
Manufacturing sector has played a significant role in determining and augmenting the G7's economic growth. Total Factor Productivity (TFP) is estimated for the G7's manufacturing sector on the foundation of Solow Residual, using FGLS technique. Trends of the TFP growth is discussed and portrayed for the time frame of 2000 to 2022. The structure of the path of TFP scores is distinctive for each member of the group. The findings of the study advise policymakers to strengthen innovation-related R&D and skill advancement to augment productivity.

Keywords: Total Factor Productivity, manufacturing sector, G7, CIPS unit root test, Feasible Generalized Least Square

1. Introduction

Beyond merely producing tangible commodities, manufacturing is the epitome of human creative ability, the basis for large-scale employment creation, and a driving force behind social advancement. G7 is the collection of the most advanced and wealthiest seven nations, comprising Canada, Germany, the United Kingdom, Japan, France, the United States of America and Italy.

Informally, these seven largest industrialized democracies formed the G7 in the 1970s. Promoting coordination, collaboration, and communication about financial and economic issues was its main objective. During the Cold War, the G7 provided a venue for discussing global economic concerns as well as trade, monetary policy, and economic stability. As time went on, the G7's agenda grew to include more general geopolitical matters like development, security, and sustainability of environment **(Mahida, 2024).** The G7 offers a prime instance of how economic resilience may be maintained through industrial development.

It is believed that variations in productivity levels are the root source of wealth disparities among economies (**Syverson, 2011).** One idea that forms the basis of TFP measurement is the Solow residual. The term "residual" is frequently used to define the amount of output growth in an economy that cannot be accounted for solely by the accumulation of capital and labor. Rather, TFP is ascribed to labor force proficiency, technology advancements, efficiency gains, and other, more difficult-to-quantify factors.

GDP growth is driven by TFP **(Akinola & Bokana, 2017). Miller & Upadhyay (2000)** estimated TFP for the 83 countries, including both developed and developing economies, using a parsimonious formulation of the aggregate production function that included labor force, capital per worker, and output per worker —both with and without the inclusion of the human capital stock. The TFP in India was examined econometrically by **Malik et al. (2021)** for the years 1980–2016.

The efficiency with which labor and capital are used to generate output is measured by TFP. It is frequently seen as a sign of advancements in technology. In a thorough analysis comparing TFP in the BRICS and G7, **Camioto & Pulita (2022)** found that while BRICS countries are currently falling behind in terms of efficiency and technological breakthroughs, they are gradually improving. On the other hand, the G7 countries exhibit greater levels of productivity, particularly in the industrial sector, as a result of their sophisticated technological infrastructure and well-established industrial processes.

Using the growth accounting technique, **Majeed et al. (2010)** calculated TFP for Pakistan's large-scale manufacturing sector from 1971 to 2007. As per **Madheswaran et al. (2007),** technological development rather than alterations in technical efficiency is the primary driver of the manufacturing sector's TFP growth in the Indian economy. Based on sector-level statistics and a Stochastic Production Frontier, they examined the growth of TFP in India's manufacturing sector from 1979–1980 to 1997–1998.

TFP levels in the manufacturing sectors of sixty-three countries were evaluated by **Harb and Bassil (2023)** over a 40-year period. They found that TFP rose in every country, despite a noticeable decline in 2008 brought on by the financial crisis. The highest manufacturing productivity is seen in the industrialized economies. Some nations had notable increases in output, which allowed them to advance. As a result, productivity rose throughout the age in all sectors and regions.

The Olley and Pakes control function method, the Greene "true" random effects stochastic frontier model, the Solow residual approach, and non-parametric data envelopment analysis (DEA) using the Malmquist productivity change index were the four methods **Männasoo et al. (2018)** used to estimate TFP growth. Using the stochastic frontier model, **Mastromarco & Zago (2012)** calculated TFP for the years 1998–2003. Human capital was calculated using the mean number of years of education among the workforce and the technology spillovers for each company. Also used firm-level data to analyze the role of public infrastructure, financial development, and R&D spillovers. They discovered that human capital, technical investments and spillovers, regional banking inefficiencies, and all other factors had a major influence on TFP growth. Furthermore, the study discovered that R&D spillovers have an impact on output in all three simulated channels, indicating that they can be significant for both inventive and adopting organizations.

Jajri (2007) used the DEA approach to calculate changes in the production frontier and the Malmquist productivity index to break down TFP into technological and technical efficiency change in order to investigate the TFP growth rate and factors influencing TFP growth in Malaysia from 1971 to 2004. It has been suggested that demand intensity, capital structure, economic restructuring, education and training, and technical advancement could all be factors in TFP.

Ascari & Cosmo (2005) investigated the primary drivers of TFP in 20 Italian areas using a panel data technique spanning a sample period of 1985 to 2000. Using the Cobb-Douglas production function and the standard Solovian growth accounting methodology, they calculated TFP, accounting for trade, social capital, human capital (the average number of years of education of the workforce), research activity, and the total number of researchers as drivers. They discovered that the variables pertaining to human capital and research activities both had positive statistical significance. Therefore, the definition of Solow residuals is significantly influenced by technical advancement, and TFP benefits from the beneficial trickle-down effect of skilled labor and human capital. Social capital and trade, however, are insignificant even at the 10% level.

Easterly & Levine (2001) documented the five stylized facts of growth: economic activity is highly concentrated; policies are closely linked to long-term economic growth rates; income varies over time; growth is not persistent while factor accumulation is; and TFP (residual) is primarily responsible for income and growth differences between nations. They claimed that OECD economies are more productive than non-OECD economies globally. TFP is described as the complex social process in gest **(Islam, 2001).**

2. Methodology

Utilizing the growth accounting framework and the Feasible Generalised Least Square (FGLS) technique, the TFP of the manufacturing sector is evaluated grounded on the Solow residual approach. Variables used to calculate TFP is mentioned in table 1.

Table 1: Variables used to calculate TFP

Variable	Definition	Data Source
Dependent Variable		
MVA	Manufacturing Value Added, constant 2015 US$	United Nations Industrial Development Organization
Independent Variables		
L	Total labor force	World Development Indicators
K	Gross capital formation, constant 2015 US$	

Source: Author's processing

Our investigation has specifically focused on Section C (Manufacturing) of the International Standard Industrial Classification (ISIC – Rev. 4) of all economic activities. A standard method for classifying economic activities, ISIC enables companies to be grouped according to the kind of activity they engage in. Value-added is the net production that remains after excluding intermediate consumption from output.

3. Model framed the estimation of TFP

In **1956, Solow and Swan** contributed to the development of neoclassical growth theory, which made productivity its primary concept. They framed a growth model for competitive economies. Changes in labor, TFP, and physical capital determine the rate of output growth in their deterministic model. The growth accounting method, which is based on deterministic models, measures TFP as the residual component of GDP growth/manufacturing growth.

TFP was studied empirically at the nation level **(Serranito, 2017; Malik & Masood, 2021),** the industry level **(Choudhury & Das, 2018; Harb & Bassil, 2023),** and firm levels **(Tekleselassie et al., 2018; Añón Higón et al., 2022).**

The basis for the creation of our model is the Cobb-Douglas production function, as per the growth accounting approach **(Kumar & Manglani, 2023).**

$$Y = A\,K^{a}L^{b} \qquad \textbf{(Cobb, 1927)} \qquad \textbf{(eq. 1)}$$

here, Y = manufacturing value added; K= Capital; L= Labor force; a= share of capital; b= share of labor

Taking Growth per worker, $$\frac{Y}{L} = \frac{A\,K^{a}\,L^{b}}{L} \qquad \textbf{(eq. 2)}$$

(Substituting $y = \frac{Y}{L}$, $k = \frac{K}{L}$)

$$y = A\,K^{a}\,L^{a+b-1} \qquad \textbf{(eq. 3)}$$

Growth accounting,

$$\ln y = \ln A + a \ln k + (a+b-1) \ln L \qquad \textbf{(eq. 4)}$$

eq, 4 defines capital, labor, and TFP growth **(Mankiw et al, 1992)**

∵ TFP can be measured as;

$$\ln A_{it} = \ln y_{it} - a \ln k_{it} - (a + b - 1)\ln L_{it} \quad \textbf{(eq. 5)}$$

$$tfp_{it} = E_{it} \quad \textbf{(eq. 6)}$$

Where, $\ln A_{it} = TFP_{it} = E_{it}$ (E is residual term of equation 6)

Here, k= real capital stock (i.e., $\frac{GCF}{\text{depreciation rate} + g_k}$) **(Harb & Bassil, 2023)**

Here, GCF = gross capital formation, 5% depreciation rate is assumed, $g_k$is the mean of every particular economy' GCF growth rate

The variables employed align with the research conducted by **Kutu and Ngalawa (2016**), who examined the trends and dynamics of industrial production in the BRICS bloc.

The TFP scores were estimated using the FGLS methodology, as cross-sectional dependency, autocorrelation, and heteroskedasticity was found in the dataset, making FGLS a superior method to provide unbiased estimates in comparison to other panel data multiple regression techniques. FGLS is appropriate as T > N, and also, all the variables are I(1), i.e., stationary as per the CIPS unit root test (Second-generation test, applied due to the presence of cross-sectional dependency). The results of these are mentioned in the appendix.

4. Estimated TFP Scores

Table 2 demonstrates the TFP scores of G7's manufacturing sector, obtained from equation 5, applying panel ID FGLS, from 2000 to 2022. Moreover, figure 1 is the graphical representation of these TFP values.

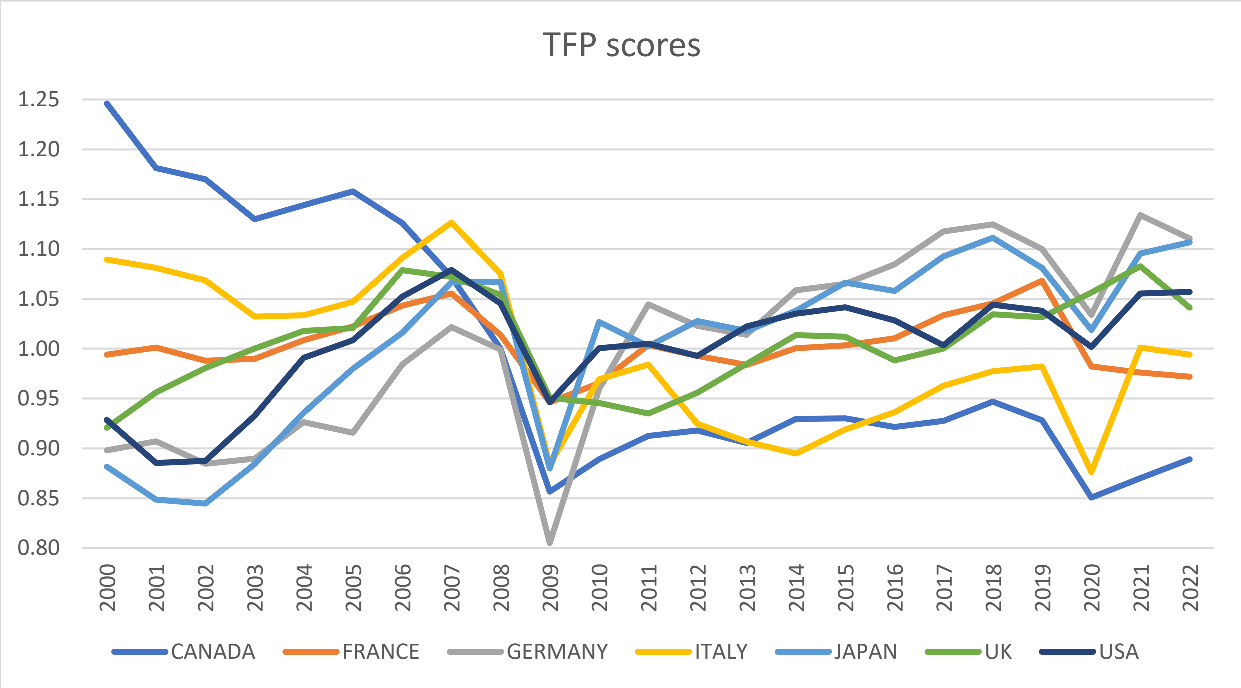
Table 2: G7's manufacturing Sector TFP scores

TFP	CANADA	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
2000	1.246	0.994	0.898	1.089	0.882	0.921	0.928
2001	1.181	1.001	0.907	1.081	0.849	0.956	0.885
2002	1.170	0.988	0.884	1.069	0.845	0.981	0.888
2003	1.130	0.990	0.890	1.032	0.884	1.000	0.933
2004	1.144	1.009	0.926	1.034	0.935	1.018	0.991
2005	1.158	1.022	0.916	1.047	0.980	1.021	1.008
2006	1.126	1.043	0.984	1.091	1.016	1.079	1.052
2007	1.072	1.055	1.022	1.126	1.067	1.072	1.079
2008	1.000	1.014	0.999	1.075	1.067	1.054	1.045
2009	0.857	0.946	0.805	0.884	0.880	0.951	0.946
2010	0.889	0.966	0.959	.969	1.027	0.946	1.000
2011	0.912	1.004	1.045	0.984	1.002	0.935	1.005
2012	0.918	0.993	1.023	0.925	1.028	0.956	0.993
2013	0.906	0.984	1.014	0.907	1.018	0.985	1.022
2014	0.930	1.000	1.059	0.895	1.038	1.014	1.035
2015	0.930	1.003	1.065	0.919	1.066	1.012	1.041
2016	0.922	1.010	1.085	0.936	1.058	0.988	1.028
2017	0.927	1.033	1.118	0.963	1.093	1.000	1.003
2018	0.947	1.045	1.125	0.977	1.111	1.034	1.044
2019	0.928	1.068	1.100	0.982	1.081	1.031	1.038

2020	0.851	0.982	1.034	0.876	1.019	1.056	1.002
2021	0.870	0.976	1.134	1.001	1.096	1.083	1.055
2022	0.889	0.972	1.111	0.994	1.107	1.041	1.057

Source: Author's processing

Fig. 1: TFP of the G7' manufacturing sector from 2000 to 2022



Source: Author's processing

Most countries had a general growth in TFP between 2000 and 2007, but the global financial crisis caused a sharp decrease in 2008 and 2009. TFP scores show that different nations have diverse recovery paths after 2009, with some recovering more rapidly and steadily than others. After 2009, countries like US, Japan, and Germany had a stronger recovery than Italy and Canada, which had a slower and more unstable recovery. By 2012, most countries had begun to stabilize and show positive trends in TFP, despite variations in recovery consistency and speed. Germany and Japan frequently have higher TFP values in the second half of the period compared to other nations, indicating higher levels of productivity. Italy's and Canada's TFP numbers are lower after 2009, which suggests slower productivity. Germany has a clear upward trend over the long term, which became particularly noticeable in 2009. Furthermore, Japan consistently improves and maintains higher TFP statistics overall, despite sporadic setbacks. Additionally, the US and the UK both recover from the crisis, but the TFP numbers fluctuate more.

The TFP numbers for the manufacturing sectors of the G7 countries demonstrate varying levels of resilience and productivity development. Japan consistently maintains a higher TFP than its G7 competitors, as demonstrated by prior studies that highlight the nation's strong emphasis on technical innovation and effective resource allocation **(Smith et al., 2018; OECD, 2020).** Conversely, TFP in other G7 nations exhibits more variable but often increasing trends, which are significantly influenced by economic cycles and responsive policy interventions **(Jones, 2019; IMF, 2021).**

The graph and series indicate a slower TFP growth rate because the G7 nations essentially have mature manufacturing units. With a slight decline in recent years, Canada's trend is generally stable, ranging from

0.857 (2009) to 1.246 (2000). France's TFP peaked in 2019 at 1.068 after starting at roughly 0.994 in 2000 and then started to drop slightly. In contrast, Germany's TFP rates remained relatively stable from 2000 to 2009 then rose significantly in the 2010s, peaking at 1.134 in 2021. TFP in Italy remained below 1.0 for most of the years, showing some volatility but generally rising in the most recent years. TFP levels for the US manufacturing sector stayed over 1.0 throughout, showing strong productivity performance with just minor fluctuations. Additionally, the UK's TFP level demonstrated stability in productivity as well, staying mostly steady with just minor fluctuations around 1.0.

The G7 group has handled the short-term swings in their productivity throughout the economic crisis and the emergence of COVID-19. The pandemic's effects are still visible in 2020, however they vary by country. Some, like Germany and the UK, showed resilience, while others, like Canada and Italy, suffered more severe setbacks.

The findings demonstrate the vital role that persistent investment in innovation and supportive economic policies play. Prior research indicates that countries that encourage technological innovation by supporting R&D and investing in digital infrastructure, for instance, typically have higher TFP growth **(Acemoglu et al., 2019).** Additionally, adaptive measures have highlighted some countries' capacity to maintain or even boost TFP in the face of global challenges like the COVID-19 pandemic **(Baldwin & Mauro, 2020).**

Since 2008, the UK has experienced weak productivity growth. According to the UK government, few companies are more productive than others in the same industry. Additionally, it stated that servitization—the blurring of the lines between manufacturing and services—is taking place in the UK economy. UK manufacturing facilities are offering services and solutions in response to consumer demand **(Vandermerwe & Rada, 1988; Neely A., 2008; Vladimirova, D., 2015).**

Before 2010, Canada's industrial productivity performance was extremely low when compared to the rest of the group. Following that, it did well due to an improvement in its ability to sustain TFP growth and consistently raise labor productivity. However, during 2000–10 and 2011–15, manufacturing lost importance in every economy except Japan and Germany. Canada saw the biggest drop, going from 19.0% in 2000–10 to 14.2% in 2011–15 **(Tang & Wang, 2020).** Germany's productivity growth has been determined to be slow because of the significant number of immigrants who are educated but lack skills **(Baily et al, 2021).**

Global economies were significantly impacted by the COVID-19 epidemic, leading to changes in consumer behavior, reduced demand, and supply chain disruptions. The TFP growth declines or stagnations that most G7 countries encountered in 2020 and 2021 were a reflection of these challenges. There are several reasons for the high or low TFP of the G7 bloc. For instance, Canada's TFP remained relatively steady at a moderate level, most likely due to efficient use of resources and investments in technology. However, France and Italy may have lower TFPs due to structural issues, regulatory barriers, and a slower adoption of innovative manufacturing technology. Germany's historically modest TFP growth has been aided by its strong industrial base; nonetheless, the energy transition and demographic shifts present problems for the nation. Japan's uneven performance has been exacerbated by its aging population and slow adoption of new technologies. The US has consistently maintained moderate to high TFP growth because of innovation, R&D spending, and a flexible labor market. The UK saw higher TFP growth linked to advancements in digital technologies, despite the uncertainty surrounding Brexit. The pandemic and subsequent government responses appear to have had an unanticipated impact on the development of productivity in industrialized economies. Despite these worries, there has been a lot of discussion and empirical evidence suggesting that the epidemic may have increased productivity in

addition to its crisis-related effects **(Abdul, 2021).** For instance, in the United States, manufacturing and other industries shown favorable within-industry productivity contributions.
Fernald et al. (2024) found two competing explanations for the slowdown in advanced economies. One is the general declining trend brought on by the Great Recession, and the other is the drop in contributions from ICT. The ICT boom has sown the seeds for its demise, claim **Aghion et al. (2023)** and **De Ridder (2024)**. The second common shock that negatively impacted the manufacturing sector's productivity in the G7 economies was COVID-19.

5. Policy Implications

To promote innovation in manufacturing procedures and product development, R&D spending needs to be increased with an emphasis on quality and customization. G7 manufacturers can preserve efficiency and concentrate on their key skills by outsourcing non-essential tasks and carefully managing supply chains.
Reducing human error and operationalizing precision are two benefits of automation and artificial intelligence. Consequently, productivity will increase if operations are streamlined for them. Governments may improve the competitiveness and efficiency of their industrial sectors and guarantee sustainable growth and development by customizing these policy recommendations.
Tailored policy frameworks that focus on technical innovation, labor market formalization, and skill development are required to increase the G7's manufacturing sectors' TFP growth. Policymakers may encourage long-term economic stability and increase productivity in a variety of economic scenarios by managing structural barriers appropriately and making good use of demographic potential.

6. Conclusion

TFP was measured for the manufacturing sector of the most advanced bloc, G7, for the year 2000 to 2022. The TFP scores have been fluctuating for all economies, having a common drop during the phase of the global financial crisis (2008) and the COVID-19 pandemic (2019-2020). The recovery path has been distinctive amongst the group nations. It is recommended to work on innovation-related research and activities and skill development to enhance TFP growth. In future, the studies could be conducted to visualize the role different variables in enhancing the productivity of manufacturing sector by regressing distinctive factors such as education, health, government expenditure, R&D, etc on the estimated TFP.

7. Appendix

Table 2 – Results of the diagnostic tests conducted

Ill-measure	**Test Applied**	**Statistics**	**Present or not**
Autocorrelation	Wooldridge test	F statistic = 20.337 Pr > F= 0.004**	Present
Cross-sectional dependency	Breusch-Pagan LM test of independence	$\chi^2 =$ 6.247 Pr= 0.00***	Present
Heteroskedasticity	Modified Wald Test for groupwise heteroskedasticity	χ^2 (7) = 349.25	Present

		Pr > chi2 = 0.00***	
Multicollinearity	VIF test	lnk VIF = 1.17 lnL VIF = 1.17 Mean VIF = 1.17	Absent

Source: Author's processing, ***, **, * portrays p-value < 1, 5, 10 % respectively

Table 3: Stationarity of the variables used

G7	At Level			At First difference			Integration Order
	CIPS Unit Root Test						
	A0	A1	A2	A0	A1	A2	
Lny	-1.987	-1.990	-1.679	-3.763***	-4.122***	-4.296***	I(1)
Lnk	-1.289	-2.245	-1.653	-2.638***	-3.538***	-3.608***	I(1)
lnL	-1.952	-2.002	-1.684	-3.323***	-3.441***	-3.851***	I(1)
A0: No constant, no trend; A1: constant, no trend (individual intercept); A2: Constant, trend; *** Denotes significance at 1%							

Source: Author's processing

Table 4: Results for the modelled production function equation to estimate TFP

G7	(1)	(2)	(3)
	FEM robust	**REM robust**	**FGLS**
Dependent Variable is lnY			
lnk	-0.004 (-1.49)	0.004 (1.48)	-0.0005 (-0.21)
lnL	-0.311** (-2.25)	-0.045 (-0.45)	-0.036 (-0.20)
Constant	14.681** (6.06)	10.010*** (5.71)	9.66** (3.24)
Statistics	Overall = 0.331	Overall = 0.315	
	F (2, 152) = 3.82	Wald chi2 (2) = 2.47	Wald chi2 (8) = 447.77
	Prob > F = 0.02	Prob > chi2= 0.29	Prob > chi2= 0.00
Hausman Test	chi2 (2) = 7.44 Prob > chi2 = 0.024		

Source: Author's processing, ***, **, * portrays p-value < 1%, < 5%, < 10%; t-statistics in bracket (FEM); z-statistics in bracket (REM, FGLS)

*Insignificance of lnk and lnL shows that there exists low labor and capital productivity in the manufacturing sector of G7

*Lower R-square depicts that only capital and labor contribute a very small portion to overall MVA. There are other relevant variables that are missing, i.e., TFP.

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