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Technological advances and their impact on productivity and standard of living – evidence from the last four decades

In this work, we investigated how productivity behaved globally and how labour productivity (LP) explained the standard of living in 1980–2019. To accomplish this, we checked descriptive statistics of productivity and compared adjusted R-squared and ANOVA F-statistics to check whether the role of LP has become more significant in explaining per capita income as a proxy for the standard of living over time. Our findings suggest that while LP grew on average, its inequality also increased. Despite all the technological changes, some countries have had significant losses in LP and some countries skyrocketed. The research demonstrates that although LP did not become a better predictor of the standard of living over time, it remains the best one there is, as the technological changes affecting LP are the same ones that are bringing better standard of living to the world. The paper highlights the need to invest in new ways and new technologies to improve labour productivity in companies and other organizations to achieve better standard of living in general.

Keywords: productivity, standard of living, advances in technology, human development

JEL classification: D24, D90, E20, O47

Introduction

In the last four decades, the world has changed in many aspects, but more than anything, it has faced significant technological advancements. These changes have had enormous consequences and have made life easier and better in an increasingly sophisticated and complex world. The pace of change is fast, its dimensions enormous, and its impacts unpredictable. Job creation, job destruction, job polarization, online operations, online meetings, 3D printing – these are just a few phenomena characterizing this new world.

Factors of production are economic inputs utilized in producing goods. Since the industrial revolution, production factors in any industry (and economy) are capital, labour, energy, materials and services (commonly called KLEMS). The most important in terms of value and productive capacity are capital (K) and labour (L). Energy, materials and services vary according to the scale of production. Capital, labour and the consequent productivity are, according to the production function, the most relevant for producing goods and determining a nation's standard of living.

Twentieth-century economists before and after the great depression of 1929 and World War II contributed to new visions and methods of measuring the volume of physical production. They also highlighted the relationship between capital, labour, productivity, economic growth, and better standard of living. Many economic theories have been born from these ideas, and many technological changes affecting the production of goods put these theories to the test. Many of them proved to be correct; some did not.

Looking for "what creates multi-factor productivity" (for the purpose of this research understood as total factor productivity), Crafts [2008] indicated two possibilities: adoption of a new technology or more efficient utilization of inputs, noting: "Business managers do not concentrate efforts to increase MFP but do so to reduce costs, create better products, and meet better production processes, which indeed leads to MFP increases".

Considering Crafts's findings and confronting them with the impact of technological changes since the 1980s, we asked: What happened to productivity and the standard of living in the last four decades? In this work, we investigated factors vital for the understanding of the impact of technological changes on productivity and the standard of living in more than one hundred nations in the last 40 years by measuring labour productivity (LP), capital productivity (KP), total factor productivity (TFP) and per capita income (PCI).

Having chosen five specific moments in time (1980, 1990, 2000, 2010, 2019), we compared descriptive statistics and performed multiple regression analyses. Taking PCI as the dependant variable and productivity measures (LP, KP, TFP) as the only three explanatory variables, we compared the R-squared and the F-statistic over time to help understand how the enormous technological changes may have affected the explanatory power of productivity over PCI as a proxy for global standard of living.

Our research aims to fill a gap in the literature on the productivity of labour and capital by clarifying long-term productivity issues and deepening the knowledge of how the last 40 years of enormous social and technological transformations have impacted the productivity of workers and the standard of living in the world.

1. Literature review

Recent technological advancements have led to an increase in productivity and a reduction in production costs, boosting the supply of goods and services at a low cost. Furthermore, they are linked with increasing levels of income (measured indirectly as GDP per capita) and improving standards of living [Kanga et al., 2022], as well as improvements in communication, business, transportation, education, healthcare, development and governance of modern cities, and resource accessibility [Javed et al., 2022].

Technology has also improved the productivity and efficiency of business. It is used as a tool to foster innovation and creativity by facilitating collaborative interactions through teamwork, online meetings, team rooms, web conferencing, and file sharing. Furthermore, it provides an inexpensive and fast way of online communication [Javed et al., 2022]. Companies can now use different cloud-based services and applications for accounting, invoicing, human resources, as well as document storage and backup at a reasonable cost. Technology has also contributed to reducing the number of employees who get injured at work. Automated systems are used in manufacturing instead of manual systems, lowering the costs of hiring employees.

A study conducted by Aly [2022] into the effect of the digital transformation on selected developing nations produced both pertinent and intriguing conclusions. In the study, individual indices capturing particular aspects of the digital transformation were replaced with a single composite indicator comparable across the group of analysed companies. The results showed a positive correlation between the employed digital transformation index on the one hand and employment, labour productivity and GNI per capita on the other. The rise in overall employment was attributed to the correlation between female employment and the digital transformation in emerging economies, and that was predicted to benefit women more than men.

Furthermore, technology – including software engineering, computer technology, telecommunications networks – reduces production errors and labour costs, thus increasing productivity and accuracy of production processes [Aly, 2022]. It also improves productivity and output in business by providing reliable and accessible database systems. Moreover, technology has led to an international business transformation through the advent of e-commerce. Nowadays, businesses conduct their trade on international online markets, giving customers a continuous access to a pool of products and services.

The fourth industrial revolution resulted in unprecedented changes in the healthcare system. E-health uses emerging information and communications technology to enable and improve healthcare services [Lintonen et al., 2008]. For example, cell phone technology has opened many doors in health awareness and medical translation, enabling poor communities found in parts of Africa, China and India to receive awareness alerts regarding tuberculosis, HIV and AIDS. Moreover, technology assists with the development of vaccines, which plays an important role in disease prevention and mortality reduction. In addition, online banking has revolutionised the livelihoods of many people who have no access to good roads.

Governments use technology to deliver citizen services and to improve national defence and security. An essential component of citizen policy strategy, particularly during the COVID-19 epidemic, was electronic governance. By integrating new technologies, e-government services, social media, mobile services, customized user accounts, e-participation and citizen information services, companies can establish direct communication with the government and citizens and maintain service quality [Hariguna et al., 2021].

Artificial intelligence has a significant impact on achieving sustainable development goals, especially when it comes to reducing poverty and enhancing the safety and dependability of infrastructure, which enables economic growth and development in emerging nations. Recent findings show that AI is transforming agriculture, education and the banking sector through financial inclusion, as well as boosting the collection of data on poverty through poverty maps [Mhlanga, 2021].

Computers with internet access help people to find online jobs, facilitate training, literacy and learning. Technology has improved communication, thus making education accessible to everyone. The Internet enables people to exchange ideas, views and opinions through online discussions. Technology first equipped the education sector with massive, immobile machinery, to now provide it with compact, hand-fitted smart gadgets [Oke, Fernandes, 2020]. A lot of studying is now done online, virtually connecting teachers and students and facilitating the distribution of learning materials. Online learning is undoubtedly one of the most popular alternatives to higher education [Djalilova, 2020].

Digital learning tools used in classrooms facilitate and expand the scope of learning, improve student participation and reduce the cost of education. Communication takes place through portals, the intranet, chats, video conferences, voice over IP, helpdesks and well-maintained user-friendly websites equipped with self-assessment tools to make sure that students are appropriately interacting with the subject matter [Schneider, Council, 2021].

Despite its benefits, technology has certain disadvantages. It has negatively affected human interactions and socialisation, and has led to widespread unemployment. Moreover, its application in the healthcare sector has led to controversial medical practices such as stem cell research and to concerns about private clinics providing unregulated therapies based on scant research due to hasty regulatory clearance based on insufficient clinical data [Fears et al., 2021]. Moreover, lack of exercise and sleep due to prolonged screen time may lead to health problems such as headaches, backaches and vision disturbances [Rashid et al., 2021].

Technology has become a crucial part of our life. It has increased productivity, thus increasing the supply of goods and services at a low cost, which in turn translates into increased purchasing power of consumers. On the one hand, automation, AI and robotics might provide substitutes for a broad range of human skills; on the other hand, technological advancements create new job opportunities, generate income and increase the standard of living, thus presenting incredible social and economic opportunities.

2. Theoretical framework

The workforce is a crucial aspect of productivity computation and is defined as the sum of employed and unemployed people (and as such excludes those who do not seek employment, such as full-time students, homemakers, pensioners). Capital (K) refers to everything the workers use to produce consumer goods or services, including tools, equipment and infrastructure. Labour (L) is the time spent by them in the workplace. Based on models rooted in the analysis of the circular flow of money in an economy – the so-called general equilibrium model – and organized under neoclassical assumptions, economists express their relationship mathematically as:

$$Y = F(K,L) \tag{1}$$

This equation shows that production is a function of capital and labour. More goods are produced with the same capital and labour if a new, more efficient production method is developed. Available technologies limit production under the given quantities of capital and labour.

The Cobb–Douglas production function presented in *A theory of production* [Cobb, Douglas, 1928] clarifies that production depends on capital and labour and is influenced by technology that determines the productivity of those factors. It assumes that capital, labour and product are so closely related that, with the available technology, multiplying labour and capital by x would also increase production by x.

$$Y = AF(K,L) \tag{2}$$

Y – real output produced in a given period,
F – function relating output to capital and labour,
A – total factor productivity,
K – capital input,
L – labour input.

For any value of capital and labour, an increase in productivity (A) implies an equivalent increase in the output produced. Thus, increases in productivity correspond to any improvements in the economy that allow capital and labour to be utilized more effectively.

Based on the assumptions of marginal productivity, where capital yield is calculated as $MPK \cdot K = \alpha Y$, and labour yield as $MPL \cdot L = (1-\alpha)Y$, Cobb and Douglas demonstrated that:

$$F(K,L) = A\ K^{\alpha}\ L^{(1-\alpha)} \tag{3}$$

Since A is the parameter that measures the effect of the available technology, a technological advance that increases A also increases the marginal product of both factors proportionally – with a correction by 'α and 1– α' – as the function has constant returns of scale.

The marginal products of scale of the Cobb–Douglas production function are:

$$MPL = (1-\alpha)Y / L \tag{4}$$
$$MPK = \alpha Y / K \tag{5}$$

Y / L – average productivity of labour,
Y / K – average productivity of capital,
α and $1-\alpha$ – production elasticities of capital and labour.

In the quantitative research work *Productivity and economic progress*, Rostas [1954] examined two questions: What proportion of the national product increase came from labour input increment and productivity factor increment, respectively? And how far has the increase in national product contributed to economic progress? The relative magnitudes involved clearly show that productivity has played a significant role in advances in consumption and capital expansion that constitute economic progress.

Other fundamental works, such as *Productivity trends: Capital and labour* [Kendrick, 1956], *The production function and the theory of capital: A comment* [Champernowne, 1953] and *Resource and output trends in the US since 1870* [Abramovitz, 1956], had also shown the essential impact of production and productivity on improving the standard of living.

The relation of output to tangible inputs can be measured again in total factor productivity. Output, capital and labour are measured directly, while the productivity index A is measured indirectly by assigning to A the value necessary to satisfy the equation (remembering that $0 < \alpha < 1$):

$$A = Y / (K^{\alpha} L^{1-\alpha}) \tag{6}$$

Productivity is affected not only by innovation – or technological change – but reflects the advance in know-how, entrepreneurs' increments and production processes. Since the last four decades have seen considerable changes in social and technological issues, it is worth taking a look at the change in the standard of living (here measured by the proxy per capita income) as a consequence of productivity improvements (here consisting in labour, capital and total factor productivity).

Our work compares, at different moments in time, the econometric model that estimates per capita income based on productivity measures, following the basic multiple linear regression equation:

$$PCI_{it} = \beta_0 + \beta_1 LP_{it} + \beta_2 KP_{it} + \beta_3 TFP_{it} + \varepsilon \tag{7}$$

i – country,
t – time period,
PCI_{it} – per capita income in country i over the period t,
ε – error term.

3. Data gathering and research methodology

We analysed observational data for all countries with available data, excluding outliers, for 40 years from 1980 to 2019, and composed a longitudinal database with a total of 565 observations based on the Penn World Table (version 10.0).

We separated and compared measures of productivity for five different dates (cuts) spanning four decades and chosen due to their relevance for the significant technological and social changes that have been shaping the world since the 1980s:

- 1980 – right before the beginning of significant changes,
- 1990 – first test of the World Wide Web software by Tim Berners-Lee,
- 2000 – millennium bug problem expected to occur at the turn of the new century,

– 2010 – world's first iPad launch,
– 2019 – last date with data available for comparison.

An investigation following this approach could illuminate important issues and provide insights with practical implications. This methodology distinguishes itself from prior studies by upholding scientific rigor while prioritizing ultimate perceptual outcomes of a decade-to-decade change process over exhaustive mathematical computations encompassing the entire 40-year span across all nations.

In this work, we investigated how labour productivity, capital productivity and total factor productivity behave in the world over time and how the independent variables used to measure productivity affected the dependent variable, i.e. per capita income. To accomplish this, we analysed descriptive statistics for labour productivity, capital productivity and total factor productivity over time and compared adjusted R-squared, ANOVA F-statistics and probability values to check the statistical significance of the models in different moments in time, in order to see whether the role of productivity in explaining the level of the standard of living has increased.

Other variables – of minor relevance for this study – were left to the error term. No endogeneity (omitted variable bias) was considered because the intention was to compare the model with only three variables based on one database.

Before performing the regression analysis, we also checked the assumptions of linearity, normality distribution of the error terms, no autocorrelation or multicollinearity, and used robust standard errors for heteroscedasticity.

The hypotheses were elaborated with the assumption that the technological changes in the last 40 years have improved productivity. We hypothesized that, as a consequence of the vast technological advancements in the world over the last four decades:

– labour productivity, capital productivity and total factor productivity have grown,
– productivity has become a more significant predictor of the standard of living in economic models.

All the calculations were done with the following parameters:

– output-side real GDP at chained PPPs (in mil. 2017 USD),
– population and number of persons engaged (in millions),
– per capita income – as GDP per capita,
– average annual hours worked by persons engaged,
– total factor productivity at current PPPs (USA=1),
– labour productivity – average product per person-hour,
– capital productivity – average product per capital unit.

4. Exploring the data

4.1. Labour productivity

Labour productivity more than doubled (from 13.79 to 30.09), on average, in the last four decades, especially in the 21st century. However, the standard deviation more than doubled as well (from 11.34 to 24.79), and the variance almost quadrupled, suggesting that the inequality of labour productivity increased globally.

The interval measure growth (from 38.76 to 124.77) shows how big this inequality became over time. Excluding the outliers, a closer look at minimum (from 1.01 to 0.32) and maximum (from 39.77 to 125.09) values shows that productivity measures became much lower and much higher, respectively, from 1980 to 2019. This means that, although on average LP consistently grew in the world, some countries experienced significant losses in labour productivity despite all of the technological changes.

The asymmetry measure was already positive in 1980 (0.85), showing a right-skewed distribution of LP in the world. In 2019, it was even more right-skewed (1.07), denoting that a small number of countries became much more productive than others.

Table 1. Descriptive statistics for labour productivity

	1980	1990	2000	2010	2019
Average (mean)	13.7969	16.0489	20.1152	27.2565	30.0945
Median	10.9028	12.2022	14.8181	20.9544	22.5738
Standard deviation	11.3427	12.6103	18.1020	23.3365	24.7909
Variance	128.6579	159.0192	327.6833	544.5957	614.5929
Asymmetry	0.8528	0.8045	0.9451	1.1565	1.0713
Interval	38.7640	47.5480	74.0479	113.9613	124.7709
Minimum	1.0080	0.8454	0.8967	0.9584	0.3216
Maximum	39.7721	48.3933	74.9446	114.9197	125.0925
Observations	99	113	118	117	118

Source: Own calculations based on the Penn World Table (version 10.0).

4.2. Capital productivity

Capital productivity halved (from 0.51 to 0.27), on average, in the last four decades, especially in the 20th century. Moreover, the standard deviation also shrunk (from 0.40 to 0.13), and the variance reduced significantly, suggesting that the inequality of capital productivity shrinks globally. As capital productivity is a measure of goods produced per unit of capital stock, the results suggest that fewer goods are produced per unit, so more capital is needed to produce the same amount. Companies are more capital dependent.

Looking at minimum (from 0.15 to 0.03) and maximum (from 3.01 to 0.86) values, capital productivity measures confirm the expectation of uniformity, on average, in the use of technology. The interval measure (from 2.86 to 0.83) shows a definite trend for capital dependency.

The asymmetry measure was already positive in 1980 (3.56), showing a right-skewed distribution of KP worldwide. In 2019, it was much less right-skewed (1.58), denoting a growing similarity between countries regarding technology use and capital dependency.

Table 2. Descriptive statistics for capital productivity

	1980	1990	2000	2010	2019
Average (mean)	0.5062	0.3861	0.3410	0.2731	0.2693
Median	0.4103	0.3210	0.2947	0.2469	0.2292
Standard deviation	0.4019	0.2183	0.1729	0.1133	0.1278
Variance	0.1615	0.0476	0.0299	0.0128	0.0163
Asymmetry	3.5574	2.3291	1.5706	1.5610	1.5811
Interval	2.8653	1.3873	0.8701	0.5710	0.8310
Minimum	0.1462	0.1020	0.0853	0.0948	0.0328
Maximum	3.0115	1.4893	0.9554	0.6658	0.8638
Observations	99	113	118	117	118

Source: Own calculations based on the Penn World Table (version 10.0).

4.3. Total factor productivity

Total factor productivity shrank (from 0.82 to 0.63), on average, in the last four decades, especially in the 1980s. The standard deviation shrank, although not significantly (from 0.28 to 0.23), and so did the variance, suggesting that total factor productivity has been losing momentum since the beginning of the big technological changes. As the impacts of new technologies appear, total factor productivity loses ground to labour productivity.

Surprisingly, the interval measure (from 1.27 to 1.19) has not changed too much. Excluding the outliers, taking a closer look at minimum (from 0.27 to 0.05) and maximum (from 1.55 to 1.25) values reveals that in some countries total factor productivity measures became much lower, suggesting it has all but lost its explanatory power as regards productivity. This means that although, on average, TFP behaved consistently, the technological changes may have affected some countries in unimaginable ways still to be investigated.

The asymmetry measure was already positive in 1980 (0.22), showing a right-skewed distribution of TFP worldwide. In 2019, it was less right-skewed (0.12), denoting that, on average, countries achieve more equal total factor productivity.

Table 3. Descriptive statistics for total factor productivity

	1980	1990	2000	2010	2019
Average (mean)	0.8176	0.6783	0.6534	0.6358	0.6337
Median	0.8314	0.6818	0.6521	0.6446	0.6360
Standard deviation	0.2796	0.2449	0.2984	0.2332	0.2310
Variance	0.0781	0.0600	0.0891	0.0544	0.0534
Asymmetry	0.2177	0.1276	0.2077	0.1376	0.1231
Interval	1.2748	1.0499	1.1191	1.0650	1.1945
Minimum	0.2727	0.2258	0.1424	0.1643	0.0543
Maximum	1.5476	1.2757	1.2615	1.2293	1.2489
Observations	99	113	118	117	118

Source: Own calculations based on the Penn World Table (version 10.0).

5. Testing the hypotheses

As previously mentioned, our hypotheses were elaborated with the assumption that the technological changes in the last 40 years have improved productivity. If, hypothetically, the role of productivity in explaining per capita income has become more significant, we would expect to see R-squared and F-statistics growing consistently over time (showing that productivity explains the standard of living better and better and confirming the model's overall explanatory power gain, respectively).

Test 1. Labour productivity changes in the last 40 years

H0: Labour productivity did not increase, on average, in this period.
H1: Labour productivity increased, on average, in this period.

As shown in Table 1, labour productivity more than doubled (from 13.79 to 30.09), on average, in the last four decades, especially in the 21st century.
The null hypothesis was rejected.

Test 2. Capital productivity changes in the last 40 years

H0. Capital productivity did not increase, on average, in this period.
H1. Capital productivity increased, on average, in this period.

As shown in Table 2, capital productivity halved (from 0.51 to 0.27), on average, in the last four decades, especially in the 20th century.
The null hypothesis was not rejected.

Test 3. Total factor productivity changes in the last 40 years

H0. Total factor productivity did not increase, on average, in this period.
H1. Total factor productivity increased, on average, in this period.

As shown in Table 3, total factor productivity shrank (from 0.82 to 0.63), on average, in the last four decades, especially in the 1980s.
The null hypothesis was not rejected.

Test 4. Productivity as predictor of per capita income changes in the last 40 years

H0. Productivity did not become a stronger explanatory variable for per capita income.
H1. Productivity became a stronger explanatory variable for per capita income.

Our findings suggest that productivity did not become a better predictor of the standard of living. The explanatory power of LP, KP and TFP to predict per capita income is lower now than four decades ago. The adjusted R-squared is lower than before, and so is the overall significance of the model, checked by F-statistic, although it remains a good fit.
The null hypothesis was not rejected.

Table 4. Multiple linear regression for per capita income

Statistical multiple regression					
year	1980	1990	2000	2010	2019
multiple R	0.973005	0.967264	0.970729	0.941037	0.947107
R-squared	0.946738	0.935601	0.942314	0.885551	0.897011
adjusted R-squared	0.945056	0.933828	0.940796	0.882512	0.894301
standard error	2110.829	2773.776	3854.115	7438.605	7664.95
observations	99	113	118	117	118
ANOVA					
year	1980	1990	2000	2010	2019
F-statistic	562.8824	527.8533	620.7434	291.4461	330.9725
P-value	0.000	0.000	0.000	0.000	0.000

Source: Own calculations based on the Penn World Table (version 10.0).

Conclusions

In this work, we intended to capture a sense of how technological progress affected, on average, global productivity and its role as a predictor of the standard of living.

Our findings suggest that:

– labour productivity more than doubled (from 13.79 to 30.09), on average, in the last four decades, but its inequality increased,
– although on average labour productivity has consistently grown in the world, some countries have experienced significant losses in labour productivity despite all of the technological changes,
– a small number of countries became much more productive than others, even controlling for outliers,
– capital productivity halved (from 0.51 to 0.27), on average, in the last four decades,
– capital productivity became more equal in the world and companies became more capital dependent,
– total factor productivity shrank (from 0.82 to 0.63), on average, in the last four decades, especially in the 1980s,
– there is enough evidence to believe that the technological changes that occurred in the last 40 years may have affected some countries in unimaginable ways still to be investigated,
– excluding outliers, on average, countries achieve more equal total factor productivity,
– productivity did not become a better predictor of the standard of living, but overall the model remains a good fit.

Labour productivity showed itself to be the root of per capita income and the standard of living. Kazekami [2020] confirms this finding and even suggests that appropriate telework hours improve productivity, and are more efficient for workers that commute.

According to Diao et al. [2019], "growth has accelerated in a wide range of developing countries over the last couple of decades, resulting in an extraordinary period of convergence with the advanced economies. From the lens of structural change – the reallocation of labour from low- to high-productivity sectors, recent growth accelerations were based on either rapid within-sector labour productivity growth (Latin America) or growth-increasing structural change (Africa), but rarely both at the same time".

Ekkehardt et al. [2019] express concern about the latest technological advancements and the development of AI, which on the one hand may bring potential productivity gains, especially for low-skilled workers and developing nations, but on the other, may result in job loss and inequality. Addressing inequality requires policies beyond skill development, including digital economy regulations and profit sharing. The authors call for a cautiously optimistic approach to the opportunities and risks related to AI, stressing the importance of tailored policies and cooperation among policymakers and social partners.

Upon a comparative analysis with extant literature, our findings align with prevailing conclusions and apprehensions regarding the implications of technological advancements, specially AI. However, our contribution distinguishes itself by a more expansive temporal scope, encompassing a duration of four decades. This broader vantage point enables a more nuanced and comprehensive assessment of the subject matter, affording insights that transcend narrower temporal confines of other scholarly endeavours. Through this protracted perspective, we illuminate a trajectory of convergence in apprehensions and substantiate a congruence of concerns, thereby augmenting the scholarly discourse surrounding the ramifications of AI.

Of relevance to policy makers is the fact that an increasing standard of living comes from increasing labour productivity, and this involves a multifaceted approach that encompasses various strategies aimed at enhancing efficiency, engagement and output. Some key steps to help improve labour productivity beyond technological investments and wise use of technology are: setting clear expectations, providing adequate training, offering incentives, providing a positive work environment, promoting continuous improvement and supporting work-life balance.

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