

The heterogeneity impacts of digital transformation, human capital, and trade openness on income and labour productivity in Vietnam

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ABSTRACT

Improving labor productivity and per capita income are top priorities in Vietnam's economic policy for the next decade. This study aims to explore the heterogeneous impacts of digital transformation, human capital, and trade openness on income and labor productivity in the Vietnamese economy from 1990 to 2018. The empirical results, obtained through the quantile regression method and Bayesian inference, unequivocally demonstrate that digital transformation and trade openness significantly promote labor productivity and income improvement. Moreover, the increase in human capital unequivocally enhances income and supports the rise in labor productivity. The Granger causality test reveals a unidirectional causality running from digital transformation to income and no causal relationship between digital transformation and labor productivity. Based on these findings, we recommend that the government and businesses should invest in and develop the Internet of Things (IoT), telecommunications, and network security infrastructure. These fundamental elements affect how well and successfully the digital transformation goes. Additionally, raising the caliber of the workforce ought to be taken into account.

1. Introduction

Digital transformation has emerged as a critical driver of economic growth. Research shows that the integration of new digital technologies into traditional organizational models can significantly boost productivity, efficiency, and competitiveness (Bocean & Vărzaru, 2023; László, 2023). At the macroeconomic level, digital transformation positively impacts economic growth by increasing labor productivity and capital efficiency. Digital technologies have become a fourth factor of production, alongside capital, labor, and natural resources. Countries with higher levels of digitization tend to exhibit stronger economic performance and a greater commitment to sustainability. However, the impact of digital transformation varies across countries due to structural differences in their economies, with developed economies experiencing higher growth and emerging economies benefiting more from job creation (Di Vaio, Palladino, Pezzi, & Kalisz, 2021). Overall, the evidence indicates that accelerating the digital transition, improving access to technologies, and promoting technological adaptation are crucial for driving economic growth across emerging economies.

The digital economy has grown significantly in developed countries, bringing about profound changes in various aspects of social life and creating new opportunities for economic expansion. The remarkable technological advancements, such as artificial intelligence, cloud

computing, Internet of Things, blockchain, and 5G telecommunications, have revolutionized production methods, consumer behavior, and interactions between governments, companies, and individuals. Economists and managers are well aware that digital transformation is not just a passing trend, but a global phenomenon that is reshaping economies worldwide. In 2016, the digital economy accounted for 22.5% of the global economy, illustrating the scale of this transformation. Research by Kvochko (2013) shows that digital transformation has driven economic growth by 1.4% in emerging markets and 2.5% in the Chinese economy. However, unlike developed countries, slower or developing countries face resource limitations. They must assess the impact of digital transformation on economic growth and carefully select the areas and technologies through which they can gradually transition to a digital economy, replacing traditional production and management methods. Therefore, it is crucial to examine the impact of digital transformation on economic growth at quantiles, allowing governments to allocate resources more strategically and focus on critical goals, rather than dispersing investments across multiple areas.

Human capital cannot be ignored when studying factors that affect labor productivity. Human capital, measured by factors such as education, training, and experience, has been shown to play a significant role in driving labor productivity. Research indicates that higher levels of human capital, particularly in the form of employee education and training, are positively associated with increased labor productivity (Jibir, Abdu, & Buba, 2023). Studies have found that more educated and skilled workers tend to be more productive, as they are better able to adapt to new technologies, innovate, and utilize resources more efficiently. Furthermore, investments in employee training have been linked to productivity gains, as they enhance the skills and capabilities of the workforce. The relationship between human capital and labor productivity has been observed across various sectors, including manufacturing, services, and agriculture.

Likewise, trade openness has been shown to positively impact labor productivity. Research indicates that higher levels of trade openness, measured by the ratio of exports and imports to GDP, are associated with increased labor productivity. This relationship is attributed to several factors, including greater access to imported intermediate inputs, exposure to international competition, and the reallocation of resources to more productive firms and sectors. However, the strength of this effect varies across countries, with developed economies and those with higher overall productivity levels experiencing more substantial productivity gains from trade openness. Conversely, countries heavily dependent on primary commodity exports may see lower labor productivity due to the “Dutch Disease” phenomenon, where resource wealth can crowd out more productive economic activities. Overall, the evidence suggests that promoting trade openness while also addressing structural factors that influence productivity is crucial for driving economic growth through labor productivity improvements (Kacou, Yacouba, Talnan, & Mehmet, 2022).

The undeniable success stories of economies such as Korea, Singapore, Taiwan, China, and India are compelling evidence of the role of digital transformation and human capital in improving labor productivity. As the digital revolution becomes a defining force on a global scale, understanding how digital transformation influences income and labor productivity is paramount, especially in developing countries. Vietnam is an emerging country with a low level of human capital and labor productivity (Nguyen, Luong, & Bui, 2019). According to the General Statistics Office of Vietnam (GSO) (2024), the country’s labor productivity achieved a value of \$18,792, corresponding to 10.25% of Singapore, 14.20% of Brunei, 24.32% of Japan, 22.67% of South Korea, 33.02% of Malaysia, and 59.15% of Thailand. Vietnam’s average labor productivity had risen from VND38.64 million per worker in 2006 to VND60.73 million in

2017. Notably, Vietnam's labor productivity by sector is among the lowest, ranking at the bottom in processing, construction, and transportation warehousing. In other sectors such as agriculture, electricity and gas, wholesale, and retail, Vietnam's labor productivity also ranks near the bottom in ASEAN, just above Cambodia. Conversely, in industries with low added value, such as mining, real estate, and financial services, Vietnam's labor productivity surpasses that of other countries in the region. Within Southeast Asia, Vietnam surpassed only Laos, Cambodia, Myanmar, and East Timor in terms of labor productivity. Therefore, the imperative to accurately assess the significance of digital transformation, human capital, and trade openness in Vietnam's labor productivity becomes even more pressing, particularly given that digital transformation remains a relatively new concept in Vietnam (Ngo, 2023). The study's contributions will be outlined in the following key points:

First, although the Cobb-Douglas production function has demonstrated the diverse influence of technological factors on production, examining these diverse effects in the Vietnamese economic context remains a challenge. In fact, the relationship between digital transformation and income, as well as labor productivity, is still controversial. When it is suggested that the application of digital technology does not always contribute to increased labor productivity and income for workers. Increasing investment in technology will easily create favorable conditions for professionals and skilled workers, but it is dangerous for manual workers lacking skills and knowledge. Moreover, we also found that most previous studies focused strongly on developed countries. Therefore, this study aims to fill this research gap and provide empirical evidence for formulating relevant policy recommendations for Vietnam, a developing country.

Second, frequency-based estimation techniques result in a single regression coefficient. If this coefficient is not statistically significant, it undermines the credibility of the proposed policy implications. To address this limitation, the article will utilize Bayesian inference to provide accurate information about the degree of influence of each independent variable on the dependent variable, along with a certain degree of probability. This analysis is essential to help Vietnam successfully establish and operate a thriving digital society. By understanding the complex relationship between these factors, Vietnam can effectively transform its economic structure, promote innovative growth models, and ultimately increase productivity levels.

2. Literature review

Solow (1956) states that approximately 50% of the economic growth in industrialized countries can be attributed to physical and human capital. The remaining 50% arises from various other factors, such as advancements in production technology, investments in research and development, improvements in worker nutrition and skills, and changes in organizational methods. In his theory, Solow (1956) highlights that economic growth derived from capital tends to be limited due to the declining marginal efficiency of capital. This decline in efficiency results from the diminishing returns associated with additional capital investments, ultimately leading to a reduced impact on economic growth. Solow's (1956) theory emphasizes the necessity of technological progress and innovation as crucial factors in sustaining long-term economic growth beyond the limitations of capital investment.

Regarding empirical studies, research on digital transformation often addresses its impact on a range of sectors, such as business, medicine, and finance, as well as its impact on economic growth and development. Bocean and Vărzaru (2023) claim that digital transformation has a positive impact on growth and development by expanding access to knowledge and technical collaboration, creating employment opportunities, and increasing labor productivity. Meanwhile,

Aly (2020) examines the connection between digital transformation (as part of the fourth industrial revolution and AI trends) and its impact on economic development, labor productivity, and employment. Using the random effects estimation method (FGLS), the author examines this relationship in 25 developing countries in 2017. The results show a positive correlation between the digital transformation index and economic development (measured by GNI per capita). According to the author's explanation, digital transformation is a catalyst for increasing productivity and a means of reducing transaction costs, two factors that have a positive impact on economic development. To support this point of view, Farhadi Ismail, and Fooladi (2012) conducted a study between 2000 and 2009 using the Generalized Method Moments (GMM) estimation method and data from 159 countries. Their goal was to clarify the connection between the use of information technology and economic growth. The results showed a positive correlation between the growth rate of real GDP per capita and the information technology usage index, measured by the number of Internet users, fixed broadband subscribers, and mobile subscribers per 100 inhabitants. In addition, this group of authors showed that the impact of information technology on economic growth is more pronounced in countries with higher per capita income. Likewise, Romanova and Ponomareva (2022) show that the high rates of digital transformation of industry in modern conditions can solve such fundamental problems as increasing labor productivity and improving the population's well-being in the industrial regions of Russia. Similarly, Park and Choi (2019) found that digital transformation has both direct and indirect impacts on the economic growth of the countries they studied. Additionally, their research revealed an interesting finding: technological innovations take longer to influence economic growth compared to other factors such as human capital, governance, and institutions.

The digital transformation process not only contributes to economic growth through income increases but also has the potential to be a driving force for promoting green economic growth and sustainable economic development. According to recent studies by Balogun et al. (2020), Elmassah and Mohieldin (2020), Goralski and Tan (2020), digital technologies such as Artificial Intelligence (AI), big data analytics, mobile technology, Internet of Things (IoT) and social platforms not only improve society and industry but are also increasingly being used to improve ecological sustainability. As a result, digital transformation not only increases work productivity but also contributes to protecting the environment.

Song, Tao, and Shen (2022) found that digitization has an obvious nonlinear positive effect on corporate labor productivity in China enterprises. More precisely, their outcomes demonstrated that digitalization had a promotional effect on labor productivity, with approximately 18% of this effect achieved through transmission and influence on human capital. This suggests that the true effectiveness of digital transformation in enhancing labor productivity is only realized within the context of high-quality human resources. Moreover, the research uncovered that the impact of digitization on labor productivity is contingent on the knowledge and skills of the workforce. Therefore, investing in the development of human capital is essential for organizations aiming to maximize the benefits of digital transformation.

The role of human capital in economic growth has been proven by numerous empirical studies. In a study by Li, Wang, and Lin (2015), the impacts of physical capital, human capital, and social capital on China's economic growth during the reform period 1981 - 2010 were analyzed. The empirical results confirm that human capital contributes to economic growth through capital accumulation and increased labor productivity. Furthermore, the study shows a shift in the impact of social capital from negligible values in the 1980s and 1990s to positive impacts in the 2000s, indicating its growing importance. Notably, a decline in the role of human capital in economic growth in China was observed between the 1990s and 2000s, a finding

consistent with studies by Azam (2019), Graca, Jafarey, and Philippopoulos (1995) on the same topic. Black and Lynch (1996) gave some reasons why human capital affects labor productivity: (i) Higher levels of education and job-specific training increase workers' knowledge, skills, and abilities, allowing them to be more productive; (ii) Healthier workers with better physical and mental well-being are more energetic, focused, and productive; (iii) Educated, skilled workers are more likely to come up with innovative ideas and creative solutions that improve productivity.

Despite of the role of exports has always been important in economic policy, the impact of trade openness on per capita income and labor productivity is still debated. Several studies point out a positive effect of trade on productivity (Frankel & Romer, 1999). Another piece of studies indicates that the positive effect of trade is not automatic and can even be harmful in some cases (Kim, Lin, & Suen, 2010). By applying the panel VAR approach to 61 countries, Kacou et al. (2022) indicated that productivity gains can make domestic market production more efficient by reducing imports and improving the structure of exports. They also recommended that commodity-based economies should improve the overall labor productivity of their economies to accelerate economic diversification.

The previous studies analyze the influence of digital transformation, human capital, and trade openness in the context of Vietnam is omitted. From our best understanding, initial research on the impact of digital transformation on economic growth in Vietnam was mainly limited to qualitative analysis. However, based on the decision of the 13th Party Congress, Nguyen (2021) proposes three solutions to promote digital transformation. First, agency, unit, and community leaders need to change their thinking and become more aware of the inevitability of digital transformation proactively and dramatically. Second, digital transformation should be implemented comprehensively and synchronously, focusing on each industry and area. Finally, the practice of digital transformation should be closely linked to creativity and the promotion of internal resources, with the ultimate goal of achieving stable and sustainable development of the country. Complementing this research, Dam and Tran (2021) emphasize the importance of rapid and strong development in the areas of technology, communications, and energy infrastructure. It is also crucial to ensure network security, build a successful e-government system, and carry out tax policy and regulatory reforms simultaneously. By applying the GMM estimation method, Huynh, Nguyen, and Nguyen (2021) reached an important conclusion. They found that a 1% increase in digital transformation, measured by the Information Technology Application Readiness Index, leads to a 0.84% increase in gross real product (GDRP) in the top eight southern economic provinces. These results highlight the essential role of digital transformation in driving economic growth in Vietnam. By adopting these proposed solutions and investing in the necessary infrastructure and reforms, Vietnam can harness the full potential of digital transformation to achieve successful and sustainable development.

3. Model and methodology

The study aims to investigate the heterogeneous impacts of digital transformation, openness, and human capital on income per capita and labor productivity in Vietnam. Based on the previous studies of Li et al. (2015), Aly (2020), the initial model is proposed as:

$$\log GDP_t = \alpha_0 + \alpha_1 \log EDT_t + \alpha_2 OPEN_t + \alpha_3 \log HC_t + \varepsilon_t \quad (\text{Equation 1})$$

$$\log PRO_t = \alpha_0 + \alpha_1 \log EDT_t + \alpha_2 OPEN_t + \alpha_3 \log HC_t + u_t \quad (\text{Equation 2})$$

Where the GDP variable denotes income per capita (at the fixed cost 2010, unit UD dollar), and the PRO variable presents labor productivity (unit US dollar/year/employed worker).

EDT variable is the digital transformation value (unit million US dollars). OPEN presents trade in good openness (unit percentage), while HC denotes human capital per person index (unit point). Two variables (GDP and OPEN) were collected from the World Bank database. The database of PRO variable is given from the website (The Conference Board, n.d). And, the digital transformation value (EDT variable) was collected from UNU Wider (n.d.). Four variables (GDP, PRO, EDT, và HC) were transformed by logarithm to smooth data, and it helps to be consistent in the unit among variables (Bertani, Raberto, & Teglio, 2020). The aim of this action is to ensure a consistent explanation of findings.

To explore the heterogeneous influences, the study applies the quantile regression introduced by Koenker and Bassett (1978). Therefore, equations (1, 2) can be written as:

$$\log GDP_t(\tau) = \alpha_0(\tau) + \alpha_1(\tau)\log EDT_t + \alpha_2(\tau)OPEN_t + \alpha_3(\tau)\log HC_t + \varepsilon_t(\tau) \quad (\text{Equation 3})$$

$$\log PRO_t(\tau) = \alpha_0(\tau) + \alpha_1(\tau)\log EDT_t + \alpha_2(\tau)OPEN_t + \alpha_3(\tau)\log HC_t + u_t(\tau) \quad (\text{Equation 4})$$

Where τ is quantile, $\tau \in \{0.1, 0.25, 0.5, 0.75, 0.9\}$. The marginal impact of $\log EDT$ on $\log GDP$ at the τ^{th} quantile, can be specified as:

$$\frac{\partial Q_{\log GDP | \log EDT}(\tau)}{\partial_{\log EDT}} = \alpha_1(\tau) \quad (\text{Equation 5})$$

According to Koenker and Bassett (1978), quantile regression offers several advantages over traditional linear regression methods: (i) Quantile regression is more robust to outliers in the response measurements compared to Ordinary Least Squares (OLS) regression; (ii) The results of quantile regression are more interpretable, as they provide insights into the relationship between variables at different points of the response variable's distribution; (iii) Quantile regression can construct prediction intervals around a point estimate, which provide a measure of uncertainty associated with the prediction, making it useful for decision-making. The marginal influences of other independent variables on the dependent variable at the τ^{th} quantile can be similarly implemented.

4. Empirical results and discussion

4.1. Descriptive statistics

Vietnam is actively striving to establish itself as a major player in the realm of digital transformation. By providing favorable conditions for domestic companies to adopt and adapt to cutting-edge global digital technologies, Vietnam has positioned itself on par with its counterparts. This Southeast Asian nation boasts impressive ambitions in terms of mobile phone penetration, and its people and businesses enjoy excellent connectivity to the Internet. In fact, Vietnam's digital infrastructure is of a notably advanced caliber, spanning across all provinces and cities, with substantial investments made by domestic telecommunication firms. Furthermore, Vietnam has emerged as an attractive destination for renowned IT giants such as Apple, Samsung, Intel, and more.

In relation to human capital, according to the General Statistics Office of Vietnam (GSO) (2024), the labor force aged 15 and above is projected to reach 52.4 million individuals by the end of 2023, marking a growth of 666,500 compared to the previous year. Of these, the urban labor force is estimated at 19.5 million people, accounting for 37.3%, while the rural labor force is expected to comprise 32.9 million people, accounting for 62.7%. It is anticipated that the number of unemployed individuals of working age will decrease by 14,600, with a total of nearly

1.07 million unemployed people in 2023. However, the youth unemployment rate remains high at 7.63%. Additionally, despite the negative impact of global economic fluctuations on the Vietnamese economy, the labor market has shown positive developments. Numerous businesses have acquired new orders, expanded their operations, and commenced key projects, resulting in an improvement in recruitment demand. Notably, emerging job opportunities in Vietnam between 2023 and 2024 will predominantly focus on artificial intelligence, digital technology, data processing, and business analysis. Consequently, various industries, such as information technology - telecommunications, construction - real estate, banking, education, financial services - consulting, and insurance, will witness the emergence of job roles related to artificial intelligence and data processing. The volatility among variables is outlined in Table 1. Accordingly, the maximum values of logGDP, logPRO, logEDT, logHC, and OPEN variables are 8.869, 9.451, 8.515, 1.017, and 208.31, while minimum values are 7.361, 8.125, 3.822, 0.528, and 66.21, respectively. The substantial difference between the minimum and maximum values of the logEDT variable suggests that the contribution of digital transformation to GDP is growing at a rapid pace. In addition, the substantial range of values for logPRO suggests a notable disparity in productivity levels. This underscores the importance of investigating and addressing the factors contributing to these disparities in productivity.

Table 1

Descriptive statistics

Variables	logGDP	logPRO	logEDT	logHC	OPEN
Mean	8.136	8.800	6.663	0.752	128.12
Standard deviation	0.454	0.383	1.293	0.752	41.19
Minimum	7.361	8.125	3.822	0.528	66.21
Maximum	8.869	9.451	8.515	1.017	208.31
Observation	29	29	29	29	29

Source: Calculated by the authors

4.2. Empirical results obtained from OLS

In the next step, the study applies the OLS technique to provide a general picture of impacting of digital transformation, openness, and human capital on income and labor productivity in Vietnam, and outcomes are presented in Table 2.

Table 2

The estimated coefficients by the OLS approach

Variables	Coefficient	Std.Error	t - statistics	Probability
Dependent variable: logGDP				
logEDT	0.182	0.014	12.48	0.000
OPEN	0.003	0.001	4.91	0.000
logHC	0.713	0.195	3.65	0.001
Intercept	6.044	0.041	147.44	0.000
R square	0.9980	Adjusted R square		0.9977

Variables	Coefficient	Std.Error	t - statistics	Probability
F statistic	4,091.34	Probability (F-statistic)		0.000
Dependent variable: logPRO				
logEDT	0.174	0.016		0.000
OPEN	0.004	0.001		0.000
logHC	0.049	0.222		0.825
Intercept	7.122	0.046		0.000
R square	0.9963	Adjusted R square		0.9959
F statistic	2,258,84	Probability (F-statistic)		0.000

Source: Calculated by the authors

Accordingly, Table 2 shows that an increase in digital transformation leads to an increase in per capita income ($\beta = 0.182$) and labor productivity ($\beta = 0.174$), significantly at the 1% level. Likewise, expanding trade openness has a positive effect on income ($\beta = 0.003$) and labor productivity ($\beta = 0.004$). Table 2 also shows that improving human capital will increase economic growth and thereby increase per capita income. However, the result of the OLS technique does not confirm the influence of human capital on labor productivity ($\beta = 0.003$, p-value = 0.825). However, the value of the R-square is very high, which might suggest overfitting. To robust these outcomes, quantile regression and Bayesian inference will be employed.

4.3. Empirical results obtained from quantile regression

Despite some positive findings from the OLS technique, it failed to explore the heterogeneous impacts of digital transformation, trade openness, and human capital on income and labor productivity. Hence, in the next step, the study utilizes quantile regression to overcome the above limitations. According to Koenker and Bassett (1978), the quantile range is 0.01 to 0.99. However, the study only uses five key quantiles, including 0.1, 0.25, 0.5, 0.75, and 0.9, to report heterogeneous effects, and the findings are shown in Tables 3 and 4.

In general, the findings by quantile regression in Table 3 are in line with the OLS findings. More precisely, both Table 2 and Table 3 confirm that three variables (logEDT, OPEN, and logHC) contribute to economic growth, thereby improving income per capita in Vietnam.

Table 3

The estimated coefficients by the quantile regression for logGDP variable

Quantiles	Variables	Coefficient	Std.Error	t - statistics	Probability
$\tau = 0.1$	logEDT	0.2036	0.0227	8.97	0.000
	OPEN	0.0030	0.0004	7.58	0.000
	logHC	0.4863	0.1710	2.84	0.009
	Intercept	6.0039	0.0443	135.38	0.000
$\tau = 0.25$	logEDT	0.1666	0.0279	5.97	0.000
	OPEN	0.0028	0.0005	5.40	0.000
	logHC	0.7845	0.2404	3.26	0.003

Quantiles	Variables	Coefficient	Std.Error	t - statistics	Probability
$\tau = 0.5$	Intercept	6.0581	0.0555	109.13	0.000
	logEDT	0.1896	0.0264	7.19	0.000
	OPEN	0.0031	0.0008	3.95	0.001
	logHC	0.5260	0.2865	1.84	0.078
	Intercept	6.0751	0.0699	86.88	0.000
$\tau = 0.75$	logEDT	0.1721	0.0407	4.23	0.000
	OPEN	0.0025	0.0009	2.63	0.014
	logHC	0.8568	0.4017	2.13	0.043
	Intercept	6.0331	0.0802	75.25	0.000
$\tau = 0.9$	logEDT	0.1682	0.0526	3.20	0.004
	OPEN	0.0025	0.0010	2.45	0.022
	logHC	0.9821	0.4882	2.01	0.055
	Intercept	5.9884	0.0882	67.92	0.000

Source: Calculated by the authors

Similarly, the estimated coefficients for the logPRO variable in Table 4, obtained through quantile regression, align with the results of the OLS technique. Surprisingly, at the 10% and 50% quantiles, human capital has a negative impact on labor productivity, although it is not statistically significant.

Table 4

The estimated coefficients by the quantile regression for logPRO variable

Quantiles	Variables	Coefficient	Std.Error	t - statistics	Probability
$\tau = 0.1$	logEDT	0.2059	0.0389	5.29	0.000
	OPEN	0.0034	0.0011	3.21	0.004
	logHC	-0.1469	0.3447	-0.43	0.674
	Intercept	7.0687	0.0798	88.60	0.000
$\tau = 0.25$	logEDT	0.1562	0.0307	5.09	0.000
	OPEN	0.0041	0.0008	5.12	0.000
	logHC	0.1038	0.2607	0.40	0.694
	Intercept	7.1409	0.0644	110.85	0.000
$\tau = 0.5$	logEDT	0.1762	0.0312	5.65	0.000
	OPEN	0.0042	0.0009	4.45	0.001
	logHC	-0.0816	0.3270	-0.25	0.805
	Intercept	7.1571	0.0871	82.18	0.000
$\tau = 0.75$	logEDT	0.1841	0.0336	5.48	0.000

Quantiles	Variables	Coefficient	Std.Error	t - statistics	Probability
$\tau = 0.9$	OPEN	0.0036	0.0011	3.29	0.003
	logHC	0.0107	0.3752	0.03	0.977
	Intercept	7.1240	0.0976	72.96	0.000
	logEDT	0.1800	0.0362	4.98	0.004
	OPEN	0.0035	0.0010	3.46	0.002
	logHC	0.1353	0.3813	0.35	0.726
	Intercept	7.0793	0.0913	77.52	0.000

Source: Calculated by the authors

4.4. Robustness

Since both approaches (OLS and quantile regression) failed to examine the influence of human capital on labor productivity, the study uses robust Bayesian inference. The main advantages of Bayesian inference are: (i) Bayesian inference allows researchers to incorporate previous information or beliefs about a parameter or hypothesis into the analysis, which can improve the accuracy and precision of the results; (ii) Bayesian methods produce results in the form of probabilities that are easier to interpret than classical p-values; (iii) Bayesian methods allow the inclusion of complex hierarchical or multilevel models that can better capture the structure of the data.

The findings in Table 5 reveal that digital transformation and trade openness significantly promote labor productivity and income improvement, with a confidence level of 100%. That means digital transformation and trade openness strongly affect income and labor productivity. Moreover, Table 5 shows that human capital has a weak positive effect on labor productivity, with a confidence level of 58.59%. All findings will be discussed in the following section.

Table 5

The robustness of the Bayesian inference

Variables	Mean	Std.Error	MCSE	Probability > 0
Dependent variable: logGDP				
logEDT	0.1820	0.0149	0.0006	1
OPEN	0.0027	0.0001	0.0001	1
logHC	0.7088	0.1991	0.0078	0.9989
Intercept	6.0432	0.0421	0.0015	1
Dependent variable: logPRO				
logEDT	0.1756	0.0172	0.0007	1
OPEN	0.0037	0.0006	0.0000	1
logHC	0.0530	0.2305	0.0079	0.5859
Intercept	7.1182	0.0468	0.0017	1

Source: Calculated by the authors

4.5. Granger causality test

Finally, the study applies the Granger causality test among variables. Table 6 and Figure 1 show that there is bi-directional causality between income, labor productivity, and human capital (p -value < 0.05), and uni-directional causality running from digital transformation and labor productivity to income. These findings imply that when human capital is volatile, it can lead to volatility in income and labor productivity. Some reasons are given to explain this conclusion as: (i) Higher levels of education, skills, and knowledge acquired through human capital investment lead to greater worker efficiency and output per worker; (ii) More advanced human capital enables workers to better utilize capital equipment and technology to boost productivity (Black & Lynch, 1996). Similarly, the causal result also indicates that digital transformation is a key factor in stimulating labor productivity in Vietnam. This conclusion will be discussed in-depth in the discussion section. In general, the causality results are in line with the outcome of quantile regression, implying that the findings are reliable and can be used to suggest policy implications.

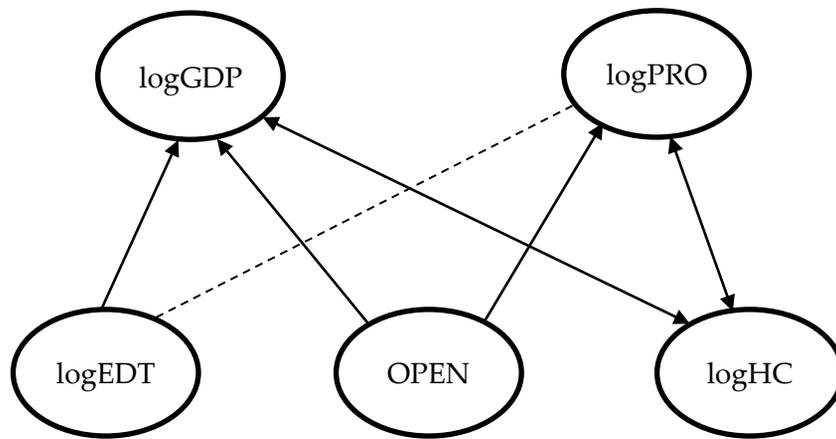


Figure 1. The Granger causality findings

Table 6

The Granger causality test results

The null hypothesis is no causality	Wald test	Probability
logGDP does not cause logEDT	2.5505	0.279
logEDT does not cause logGDP	10.024	0.007
logGDP does not cause OPEN	1.2214	0.543
OPEN does not cause logGDP	9.3135	0.009
logGDP does not cause logHC	10.016	0.007
logHC does not cause logGDP	18.548	0.000
logPRO does not cause logEDT	1.0418	0.594
logEDT does not cause logPRO	3.6600	0.160
logPRO does not cause OPEN	0.7669	0.681
OPEN does not cause logPRO	13.994	0.001
logPRO does not cause logHC	7.9116	0.019
logHC does not cause logPRO	15.995	0.000

Source: Calculated by the authors

4.6. Discussion

Regarding the impact of digital transformation on income and labor productivity, the empirical results confirm that digital transformation will support economic growth, thereby improving income. This conclusion aligns with the findings by Aly (2020), Ma and Lin (2023). Application to Vietnam's economy, this conclusion is reliable because of some reasons as: (i) Digital transformation enhances productivity by automating tasks, improving processes, and optimizing operations. This efficiency allows businesses to produce more goods and services with the same or fewer resources, leading to higher output and, consequently, increased income; (ii) Moreover, digital platforms enable businesses to reach international markets easily, expanding their customer base beyond local boundaries. This increased market reach translates to higher sales and revenue, which can contribute to higher wages and income per capita; (iii) In addition, digital technologies can significantly reduce operational costs through automation, better supply chain management, and improved resource allocation. The savings can be reinvested into the business, leading to growth and higher wages for employees (Bertani et al., 2020; Ling, Luo, Feng, Liu, & Gao, 2023).

Similarly, the empirical results also indicate that expanding trade openness will enhance economic growth and improve labor productivity in Vietnam. Some reasons are given to explain this conclusion: (i) Trade openness allows countries to access larger international markets. This expansion increases demand for goods and services, leading to higher production levels. As businesses scale up to meet this demand, they often achieve economies of scale, reducing costs and increasing profitability, which can lead to higher wages and income per capita; (ii) Trade openness facilitates the exchange of technology and innovation between countries. Exposure to advanced technologies and best practices from other countries can enhance local industries' productivity. Adopting these innovations can lead to more efficient production processes, higher quality products, and increased labor productivity; (iii) Trade openness often attracts Foreign Direct Investment (FDI), bringing in capital, technology, and management expertise. These investments can lead to new industries and the modernization of existing ones, boosting productivity and income levels (Can, Ahmed, Ahmad, & Can, 2022; Guei & le Roux, 2019).

5. Conclusions and policy implications

Digital transformation is an irreversible trend and is widely seen as the most efficient way for developing countries to bridge the gap with developed countries. Using quantile regression and Bayesian inference, this article reveals key insights for the Vietnamese economy over the period 1990 - 2018. These conclusions can be summarized as follows:

Firstly, with a confidence level of 100%, it can be concluded that digital transformation has a clear positive impact on increasing income and labor productivity. And there is a one-way causal relationship that extends from digital transformation to per capita income.

Secondly, expanding trade openness has a positive impact on economic growth and labor productivity in Vietnam. And there is a one-way causal relationship that extends from trade openness to income to labor productivity.

Thirdly, the influence of human capital on income is clear, but the influence of human capital on labor productivity is weak.

Based on empirical evidence and given the current socio-economic reality and overall context in Vietnam, this article presents the following policy implications:

A rethink is absolutely necessary. Both the government and businesses must realize that today is no longer a time of hesitation about whether or not to embrace digital transformation. Instead, the focus should be on how to carry out this transformation effectively and appropriately, according to the country's actual context and business needs. Furthermore, the sooner this change occurs, the more opportunities there will be to increase competitiveness, attract investment capital, and achieve breakthroughs in productivity and production.

Building and optimizing a digital infrastructure system is essential. While Vietnam already has a fairly robust telecommunications technology infrastructure with wide coverage and a large user base, certain aspects need to be paid attention to in order to increase the speed and ensure efficient implementation of digital transformation. These aspects include IoT infrastructure, telecommunications infrastructure, internet infrastructure, and network security infrastructure. These are crucial factors that determine the success and effectiveness of digital transformation.

In addition, improving the quality of the workforce and increasing capital investment will have a dual impact on economic growth. Quality human resources not only contribute to economic growth but are also a crucial and indispensable force in the digital transformation process. Likewise, the accumulation of capital for investment activities, including investments in digital transformation, is both necessary and urgent. These efforts must be completed in a timely manner to serve future economic development goals.

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