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ICTs and economic performance nexus: meta-analysis evidence from country-specific data

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The study explores the dynamic and complex nexus between ICTs and economic performance by applying a meta-analysis with data from 65 typical studies at the country level. The overwhelmingly significant positive effects of ICTs on economic performance are confirmed through the vote count, funnel plot, precision-effect test, and meta-regression analysis. Additionally, differential influences of ICTs on developed and developing countries are investigated. Overall, developed countries gain more benefits from ICTs, while mobile technology tends to have more potential for economic growth. Moreover, the sample size and time period the data covered affect the ICTs—economic performance effect. In contrast, the type of data does not appear to significantly influence this effect. To better understand the impacts of ICTs, the continued skepticism and periodical revisit of this topic are required. The survey provides an updated and comprehensive examination of the state of the literature and also points out that although the generally favorable influences of ICTs are emphasized, the detrimental effects of ICTs on economic performance, especially for developing countries, cannot be ignored. With insights from this review, the study suggests directions for future research.

Introduction

As key innovative stimuli, information and communication technologies (ICTs) had profound impacts on economic performance for all nations over the past few decades (Saba and Ngepah, 2022; Stanley et al., 2018; Vu et al., 2020). A wealth of research has been conducted, focusing on the causal link between ICTs and economic performance at the country level (Chatti and Majeed, 2022; Kim et al., 2021; Appiah-Otoo and Song, 2021; Dewan and Kraemer, 2000; Datta and Agarwal, 2004). However, quantitatively and determinately establishing the nexus between them has been a challenging task. Although ICTs have been recognized as effective tools to enhance economic growth and long-term productivity in many studies (Awad and Albaity, 2022; Pradhan et al., 2021; Das et al., 2016; Ng et al., 2013), others have supported that ICTs affect economic performance in conflicting or ambiguous directions

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(Nabi et al., 2022; Cheng et al., 2021; Albiman and Sulong, 2017). As a result, inconclusiveness is produced.

Some insightful arguments can explain why both the positive and negative effects of ICTs have been found on economic performance. Economic development is important for national development. The driving force behind economic development is the improvement of the professional division of labor and the rationalization of industrial structure (Jiang et al., 2020). Stimulated by ICTs, traditional industries have been transformed and upgraded (Cieślik, 2021). Meanwhile, ICTs accelerate the flow and diffusion of resources, and efficient allocation of resources optimizes the division of labor and changes the industrial structure in an advanced and reasonable way (Lechman and Marszk, 2019). Consequently, the level of economic development has also improved. Moreover, ICTs function as general-purpose technologies that enhance the production possibilities of an economy, leading to widespread productivity improvements (Bresnahan and Trajtenberg, 1995). In the event of unforeseen adverse shocks, such as the COVID-19 pandemic, ICTs exhibit significant flexibility and accessibility, thereby raising the overall economic resilience of the nation (Papaioannou, 2023). Since ICTs are continuing to progress dramatically across nations, the majority of countries can continually reap the economic benefits of them (Bahrini and Qaffas, 2019; Dedrick et al., 2014; Chakraborty and Nandi, 2011; Pradhan et al., 2014).

Although the obvious and significant positive impacts of ICTs are confirmed by scholars, the potential negative effects of ICTs are emphasized in some studies (Maneejuk and Yamaka, 2020; Maurseth, 2018; Sassi and Goaied, 2013). Due to the concept of "productivity paradox" (Nobel Laureate Robert Solow said in 1987 that computers can be found everywhere except in productivity statistics) (Solow, 1987), ICTs are not clearly related to economic growth unless they reach a critical size (Wang et al., 2021b). Moreover, despite ICTs becoming affordable in many fields (Parthasarathy and Aoyama, 2017), inequalities in developing ICTs reflect wider economic privileges and exclusions. As a result, ICTs also lose their potential to reverse inequities that already exist. Because of the Matthew effect, better-resourced areas having greater opportunities for ICTs can enjoy more economic benefits of ICTs. In contrast, underdeveloped areas can become increasingly disempowered by the digital divide, and therefore, ICTs present disadvantages and amplify inequities in such areas (Tewathia et al., 2020; Wang et al., 2021a). Undoubtedly, ICTs have complex and bidirectional effects on the economy, and a deeper understanding of ICTs—economic performance links should be paid attention to. However, it is far from sufficient to provide unambiguous evidence to fully clarify the different results, which inspires the study to render a more lucid ICTs—economic performance nexus.

In this context, the study aims to examine the relationship between ICTs and economic performance with a meta-analysis, using country-specific data. A meta-analysis is an objective approach to methodically review diverse studies with often-conflicting conclusions (Stanley and Jarrell, 2005), which is suitable for this study. The research contributes to similar studies in several ways. First, it is conducive to addressing the question of the extent to which ICTs matter for economic performance. This study is a significant attempt to provide a comprehensive evaluation of the ICTs' effects on the national economy, drawing on recently published literature. Additionally, publication bias is detected and corrected to acquire a fair evaluation. Second, it gives reasons why variation exists in mainstream research. By collecting 1082 estimates from 65 studies, the study statistically explores possible explanations for why ICTs can boost economic growth or, inversely, why ICTs fail. The number of observations in this study is larger, which distinguishes it from previous studies. Third, this study employs a mixed-methods approach, integrating both qualitative and quantitative analyses to present data more convincingly, and also provide robust data support for predicting future development trends. Other features of studies, such as the sample region, the form and time span of data, and publication-based characteristics, are also taken into consideration. It is worth noting that ICTs also exert influence on cities, firms, organizations, and individuals (Araral, 2020; Yunis et al., 2018; Palvia et al., 2018; DeStefano et al., 2018), but the topics in relation to countries are more generally, which can help to collect more samples. In addition, identifying the technological sources of economic growth from a macroeconomic perspective is important for all countries, no matter rich or poor, developed or developing, to formulate policies to make sustainable development.

The rest of the study is structured as follows. Section "Literature review" reviews the related literature on ICTs and economic performance. Section "Data and methods" collects the literature, codes the data, and describes the methods. Section "Results" and Section "Discussion" summarize, explain, and discuss the results. Section "Conclusion" presents the conclusions.

Literature review

ICTs and economic performance. The emergence of ICTs has spawned a large and growing literature on the relationship between ICTs and economic growth at the national level (Haftu, 2019; Donou-Adonsou, 2019; Pradhan et al., 2018; Kumar et al., 2018). It is widely recognized that ICTs are conducive to better economic performance and the positive effects of ICTs tend to increase over time. ICTs can facilitate immediate access to data by reducing information asymmetry to a certain extent. This reduction is helpful to improve the allocation efficiency of resources (Zhang et al., 2022) and direct resources from less productive sectors to more productive ones (Brodny and Tutak, 2022; Ran et al., 2023). Thereby enhancing industrial upgrades, reshaping the structure of the economy and boosting economic development. Furthermore, the proliferation of ICT has catalyzed the emergence of new industries and spurred advancements in traditional sectors, resulting in increased productivity, an optimized supply-and-demand dynamic, and a more integrated economic framework (Ghosh et al., 2022; Chang et al., 2023). Enjoying the benefits of ICTs is predicted to have a drastic effect on countries worldwide (Castells, 1996; Vu, 2011; Shahiduzzaman and Alam, 2014; Cieślik and Kaniewska, 2004; Bayraktar Sağlam, 2016). Vu pointed out that Singapore's remarkable success in economic development has been strongly in relation to the country's efforts to embrace the ICT revolution to promote economic growth (Vu, 2013). Sawng found that ICT investment is the driving force behind the long-term economic growth of South Korea (Sawng et al., 2021). Antonopoulos said ICTs play an important role in Greek economic growth (Antonopoulos and Sakellaris, 2009).

However, ICTs help accelerate economic growth while generating new problems (Song et al., 2020). Due to the poor basic conditions and exogenous development environment, not all countries take advantage of ICTs immediately and directly. The productivity paradox and digital divide weaken the economic benefits of ICTs for a long period of time (OECD, 2001). Hence, some scholars argue that economic performance is not better when applying ICTs (Philip et al., 2017; Ishida, 2015), and studies should also explore the potential negative and insignificant impacts of ICTs on economic growth if countries are not ready for using ICTs comprehensively or the ICT infrastructure is not built and maintained properly.

Thus, it is difficult to verify that ICTs determinately lead to better economic performance. The fact not only makes the ICTs

—economic performance nexus more or less an empirical study question, but also one needs to be examined by using a meta-analysis.

Measurement of ICTs and economic performance. ICTs disseminate quickly and advance substantively. Fixed-line telephones, televisions, and radios were the mainstream of ICTs in the past. Nowadays, the measurement of ICTs is more creative. Internet, smartphones, and cloud computing all constitute ICTs (Adkins and Moulaison Sandy, 2020). The effects of ICTs seem impressive, but the different types of ICTs' relative impacts on the economy remain vague. For example, Nguyen analyzed that mobile can positively affect financial development while the internet has a negative effect on overall financial development in 109 countries over the period of 1998–2017 (Phuc Nguyen et al., 2020). Ward found that mobile contributes more to economic growth compared to fixed lines in China, but the effects diminish with time (Ward and Zheng, 2016).

Therefore, does the type of ICTs make a difference? Do they represent a one-time-only or a reliable increase in economic growth? Is the effect of internet more obvious than telephones? All these questions need to be investigated. Normally, internet-related indicators (for example, internet or broadband penetration) (Choi and Hoon Yi, 2009; Noh and Yoo, 2008; Arvin and Pradhan, 2014; Bojnec and Fertő, 2012; Castaldo et al., 2017; Edquist et al., 2018), telephones (fixed lines and mobiles usage) (Ghosh, 2016; Gruber and Koutroumpis, 2011; Thompson and Garbacz, 2007) and a composite ICT index (it consists different ICT indicators: landlines, mobile phones, internet, broadband, etc.) (David, 2019; Latif et al., 2018; Pradhan et al., 2015; Qureshi and Najjar, 2017) are frequently selected to measure ICTs in extant literature.

Similarly, different economic indicators are chosen when testing ICTs' effects on economic performance. What kind of economic data do scholars prefer to use to detect this impact? The general sense of the term "economic performance" refers to the economic development of a country in a certain period of time. It is associated with economic growth, advancement, or productivity. Indicators such as "GDP" (Gruber et al., 2014; Jin and Cho, 2015; Ketteni et al., 2014; Koutroumpis, 2009; Kumar et al., 2016; Venturini, 2009), "GDP growth rate" (Asongu and Odhiambo, 2020; Levendis and Lee, 2013), "GDP per capita" (Czernich et al., 2011; Farhadi et al., 2012; Ghosh, 2017; Hussain et al., 2021; Saidi et al. 2015; Yoo, 2010; Sun and Zhou, 2023), "GDP per household" (Thompson and Garbacz, 2011), "total factor productivity" (TFP) (Lam and Shiu, 2010), "labor productivity" (Martínez et al., 2008), and "value-added" (Hong, 2017) are usually selected when studies set dependent variables to capture economic performance. The question of whether ICTs provide unambiguous evidence to aggregate economic growth or productivity needs to be analyzed in detail. As a consequence, the meta-analysis also explores whether it has an influence when the focus is on different types of economic performance.

ICTs and economic performance in developing and developed countries. Economic growth of a country is a desirable outcome of technological progress. However, the development stage or level of a country may influence the impacts of ICTs. In most cases, developed countries are the beneficiaries of ICTs (Kurniawati, 2021; Toader et al., 2018; Hanclova et al., 2015), but it might be too optimistic to estimate the positive effects of ICTs on developing and emerging economies (Haldar et al., 2023; Ndoya et al., 2023). Niebel indicated that developing and emerging countries are not gaining more from ICTs than developed countries (Niebel, 2018). Harb also showed that ICTs' influences on middle-income countries are hovering, but they have been a significant growth determinant in high-income countries (Harb, 2017). Developed nations have consistently derived robust economic advantages from ICTs due to their solid developmental foundations. Adequate financial resources and investments propel the evolution of ICT. The generally high educational attainment of citizens enhances their capacity to adopt and deploy ICT effectively (Ark et al., 2003; Papaioannou and Dimelis, 2007). Consequently, this fosters technological innovation, refines industrial structures, and expands opportunities for economic expansion.

The phenomenon gives rise to questioning the argument that developing countries are "leapfrogging" through ICTs. It is even possible for ICTs to have detrimental effects on their economic performance. Especially, an adverse influence might arise if advanced ICTs contribute to substituting unskilled labors within a country and widening the digital divide between countries (Rath, 2016; Cruz-Jesus et al., 2012; Çilan et al., 2009). Subsequently, negative impacts of ICTs may occur on economic development. Such considerations would imply that less-developed countries should be cautious about applying ICTs.

No doubt, ICTs have complicated and nuanced effects on countries' economic performance. Do different ICTs have a greater effect in developed or developing countries? The study is particularly interested in this, and a meta-analysis is suitable for answering the question, properly.

Data and methods

Data collection and coding. The initial point of the systematic review is to identify relevant academic papers. It begins with reviewing the citations and reference lists of some well-known studies that analyze the nexus between ICTs and economic performance (for example, Stanley et al., 2018; Polák, 2017; Cardona et al., 2013; Gómez-Barroso and Marbán-Flores, 2020). By doing this, the preliminary scope of searching in the research is defined. The Web of Science and Google Scholar are used to detect related studies. Studies with keywords, such as "ICT", "telecommunications", "internet", "broadband" or "telephone" combined with "economic development", "economic growth", "growth", or "productivity" are included. Due to the breadth of keyword searches, many studies do not fulfill the selection requirements for further analysis. So, we first browse the title and abstract of each paper before downloading, excluding papers that are unrelated to the topic of our research. Subsequently, we analyze papers that passed the initial screening. Through in-depth examination, we discard papers that fail to meet the specific criteria.

The selected studies should meet the following criteria. First, they are all quantitative analyses with quantified results. That is to say a statistical method is applied in each study. Second, an independent variable associated with ICTs and a dependent variable related to economic performance is required in these studies. Without both, there could be no ICTs—economic performance estimate. Third, multiple sampling is taken from a single study, which contributes to producing more precise estimates. Ultimately, 1082 observations from 65 studies are confirmed (all the selected studies are listed in Appendix A).

The process of study screening and selection is shown in Fig. 1. It needs both scientific measurement and manual investigation. The final database of papers not only identifies classical literature and covers main journals used by previous studies, but also extends the searching scope and updates the publish date of studies.

After selecting studies, the paper's journal, title, author, and year are recorded. In the next step, different types of effect sizes are coded to express the nexus between ICTs and economic

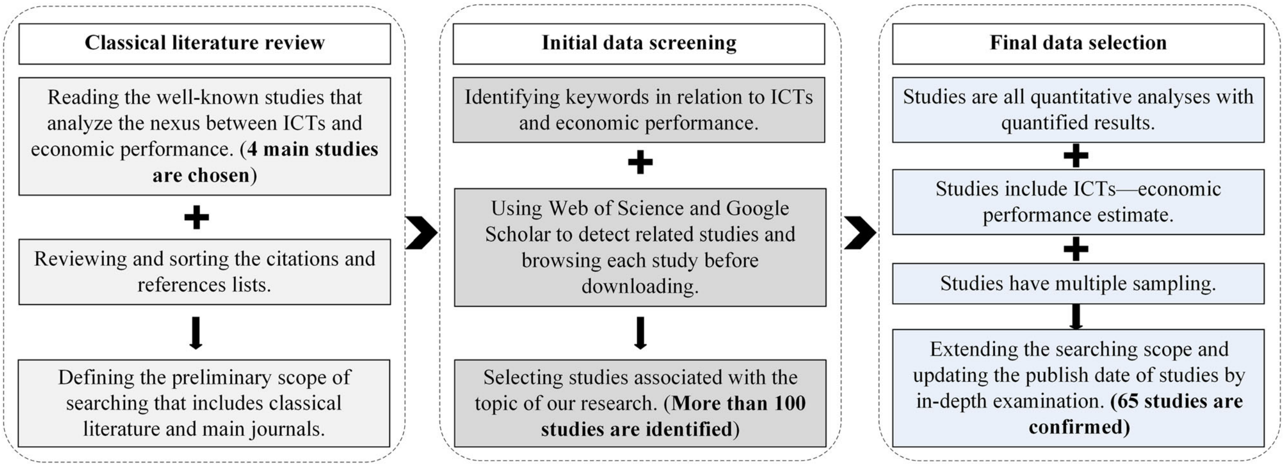

Fig. 1 The process of data collection.

performance in each study, depending upon which value the author reported. The categorical result is the most used effect size statistic since it is a measure of correlation rather than causation, which could include as many estimates as possible. *T*-statistic has also been employed to signify the nexus between ICTs and economic performance. The sample size of studies with *t*-statistics is smaller than the categorical result because not all the selected studies report this statistic. Eventually, 713 estimates are summarized from 30 studies. Subsequently, by converting each *t*-statistic to a common metric, the ICTs—economic performance effects are able to be measured according to different specifications. In this study, *Fisher's z*-transformed correlation effect size is applied.

The *Fisher's z* is formulated as follows:

$$\text{Fisher's}\, z_{ij} = \frac{1}{2} \times ln\left(\frac{1 + pcc_{ij}}{1 - pcc_{ij}}\right) \tag{1}$$

$$pcc_{ij} = \frac{t_{ij}}{\sqrt{t_{ij}^2 + df_{ij}}} \tag{2}$$

where $\text{Fisher's}\, z_{ij}$ is the Fisher's z value of the estimated ICTs—economic performance elasticity from estimate i of study j, pcc_{ij} represents the partial correlation coefficient, t_{ij} denotes the t-statistic, df_{ij} is the number of degrees of freedom.

Standard error is as follows:

$$se\_Fisher's\, z_{ij} = \sqrt{\frac{1 - Fisher's\, z_{ij}^2}{df_{ij}}} \tag{3}$$

Furthermore, the year the paper was published, the size of observations, the method of data collection, the time span the data covered, and the names of the dependent and independent variables are recorded and coded for each study.

Meta-analysis. Meta-analysis is a way to systematically review and evaluate comparable empirical studies on a specific topic. It differentiates from a traditional narrative literature review by using a statistical method (Stanley and Doucouliagos, 2012). The leading edge of meta-analysis is that it empowers scholars to compare the effects of econometric models related to the topic. In this study, the various effects of ICTs on economic performance are identified by the meta-analysis. Variations of ICTs' effects in single studies can be recognized and explained by the selected variables.

A main step of the meta-analysis is accommodating the impacts of publication bias. The publication bias occurs in the following two ways. First, scholars tend to choose statistically significant results that are consistent with conventional opinions. When selecting models, they prefer to use the model that will generate expected outcomes. Second, editors and reviewers are inclined to accept papers that match the views of existing research or publish papers with favorable and popular results. In summary, publication bias means an excessively large proportion of more significant results in the studies. Therefore, if the literature itself has a publication bias, even a careful literature review will not result in an accurate literature review (Lang and Long, 1992; Doucouliagos et al., 2012).

A funnel plot is a straightforward method to vividly illustrate publication bias in reported empirical results from different studies. It is also the most common diagram drawn in the meta-analysis, which is a scatter graph of estimates on the *x*-axis against their precision (i.e., standard errors of estimates) on the *y*-axis. Besides, a simple meta-regression model can objectively and statistically assess the genuine effects of ICTs on economic performance beyond publication bias, which is seen as a precision-effect test. A formal test based on Fisher's z is conducted:

$$Fisher's\, z_{ij} = \beta_1 + \beta_0 \times se\_Fisher's\, z_{ij} + \varepsilon_{ij} \tag{4}$$

where ε_{ij} is the estimate error, publication bias and empirical effects of ICTs exist if the constant β_1 and β_0 is significantly different from zero, respectively.

Finally, a multiple meta-regression analysis (MRA) can be further applied to investigate the effects of different study characteristics on findings. The data collection and coding process shows the existence of different measures of ICTs (i.e., internet and broadband, fixed line and mobile phone use, and ICT index) with economic performance (the main measurement of it is GDP, GDP per capita, and productivity) in both developing and developed countries. Hence, the purpose of using MRA is to peer through the potential publication bias and in-depth analyze the impacts of ICTs on different economic performances and how these impacts are influenced by a specific ICT and by the development level of a country.

Setting the categorical result as the dependent variable, the MRA is conducted based on a meta-regression model taking the multinomial logit form:

$$mlogit(ICT\_result) = F(a) \tag{5}$$

Table 1 Variables used for meta-analysis.

Dimension	Variable	Definition	Mean (SD)
(1) Dependent variables	ICT_result		1.68 (0.895)
	ICT_p	=1, if the findings of ICTs are significantly positive	
	ICT_n	=2, if the findings of ICTs are significantly negative	
	ICT_i	=3, if the findings of ICTs are insignificant (base)	
	Fisher's *z*	Conversion form of *t*-statistic	0.13 (0.250)
(2) Measurement of ICTs	ICT_measu		2.11 (1.077)
	internet	=1, if ICTs are measured in internet or broadband	
	teledensity	=2, if ICTs are measured in fixed line or mobile	
	ICT_index	=3, if ICTs are measured in a compound ICT indicator	
	ICT_other	=4, if ICTs are measured in other ways removing the above three types	
(3) Measurement of economic performance	Eco_measu		1.72 (0.507)
	GDP	=1, if economic performance is measured in GDP	
	GDP_per	=2, if economic performance is measured in GDP per capita	
	prod	=3, if economic performance is measured in productivity	
(4) Development effects	Dev_effects		1.82 (0.874)
	dev_ing	=1, if estimates concern ICTs in developing countries	
	dev_ed	=2, if estimates concern ICTs in developed countries	
	dev_both	=3, if estimates concern ICTs in both developing and developed countries	
(5) ICTs in developing countries	Dev_ict		1.76 (0.627)
	dev_int	=1, if estimates concern internet or broadband in developing countries	
	dev_mob	=2, if estimates concern mobile phones in developing countries	
	dev_fix	=3, if estimates concern fixed-line telephones in developing countries	
(6) Region	Region_var		5.40 (3.669)
	Asia	=1, if the study is conducted in Asia	
	Africa	=2, if the study is conducted in Africa	
	Europe	=3, if the study is conducted in Europe	
	G20	=4, if the study is conducted in G20 countries	
	OECD	=5, if the study is conducted in OECD countries	
	reg_other	=6, if the study is conducted in other countries removing the above five regions	
	developed	=7, if the study is conducted in developed countries	
	developing	=8, if the study is conducted in developing countries	
	h_income	=9, if the study is conducted in high-income countries	
	lm_income	=10, if the study is conducted in low- and middle-income countries	
	worldwide	=11, if the study is conducted in worldwide countries	
(7) Data type	Data_type		1.23 (0.488)
	panel	=1, if estimates relate to panel data	
	time	=2, if estimates relate to time-series data	
	cross	=3, if estimates relate to cross-section data	
(8) Sample size	number	Observations in the study	521.94 (587.157)
(9) Time span	timespan	Time period the data covered in the study	21.04 (13.353)
(10) Year of publication	Pub_year	Publish year of the study	2015.47 (4.878)
	pub_year*1*	=1, if the study is published before 2015	
	pub_year2	=2, if the study is published after 2015	

where $F(a)$ is the group of independent variables primarily consists of different study-related characteristics.

Using the Fisher's z as the dependent variable, a meta-regression model can be expressed as

$$mregression(Fishermbox's\,z) = F(a) \tag{6}$$

Table 1 provides the list of all the variables coded and used in the meta-analysis.

Specifically, not all ICTs have the same potential for economic performance, differences in the measurement of ICTs and economic performance are first examined in the multiple meta-regression model. Then, since ICTs' economic impacts depend on where they occur, development effects and various regional dummies (i.e., continent and country) are considered. Moreover, the type of moderator variable that concerns the data collection (panel, time-series, and cross-section data) is included to estimate ICTs' effects. Last, some other variables related mainly to the study and publication characteristics are also set.

Results

Vote count. Vote count can provide a rough summary of the categorical results of studies by counting the number of estimates and studies (Li et al., 2022). The distributions of findings that are significantly positive, negative, or insignificant are compared. Table 2 displays the results of the vote count in regard to the ICTs—economic performance effect based on the main study characteristics.

According to Table 2, it is prone to support the positive effects of ICTs. This is identified by the higher number of studies in the "significantly positive" category, both in the total studies and studies with different characteristics. There is an agreement that ICTs are effective tools in terms of promoting economic performance. Considering the specific study characteristics, 21% of estimates with internet, 19% of estimates with teledensity, 23% of estimates valued in developing countries, and 49% of estimates with panel data found significantly positive results; that is, ICTs related to internet, broadband, mobile phones, and fixed lines using panel data in developing countries tend to boost economic

Table 2 Vote count of the ICTs—economic performance effect based on main study characteristics.

Dimension	Variable	Significantly positive		Significantly negative		Insignificant	
		Estimates	Studies	Estimates	Studies	Estimates	Studies
Measurement of ICTs	internet	223	32	43	11	109	20
	teledensity	202	30	51	13	159	23
	ICT_index	66	10	8	4	22	7
	ICT_other	167	14	6	2	26	8
Development effects	dev_ing	253	35	55	15	219	27
	dev_ed	171	24	6	5	45	10
	dev_both	234	24	47	6	52	18
Data type	panel	535	53	94	18	238	37
	time	94	9	14	4	74	7
	cross	29	2	0	0	4	1
Total studies		658	61	108	21	316	43

1082 estimates from 65 studies.

growth in the selected studies. However, the "true" effects of ICTs might be exaggerated if the negative or insignificant estimates are negated.

Basic meta-analysis and publication bias. A basic meta-analysis is the first calculation, which is associated with *Fisher's z*-transformation values in this study. It takes 713 estimates into account, regardless of the measurement of ICTs, the development effects, or the type of data. The results of Cochrane's *Q*-test ($p < 0.01$) and *I* square value ($I^2 > 50\%$) show clear evidence of heterogeneity measured by the random-effects model. If heterogeneity exists in the reported estimates, a simple overall meta-analysis needs a further detailed interpretation. Hence, in view of the heterogeneity, 10 moderator variables are identified (see Table 1). Before the multiple MRA, the publication bias is explored, indicating how it might influence the reported ICTs estimates.

Publication bias is a serious issue. According to the vote count, the speculation of positive economic performance from ICTs is strong, so it is not surprising if insignificant or negative results are not reported or seen as a misspecification of the model. Figure 2 is funnel graphs of the impacts of ICTs on economic performance.

As displayed in Fig. 2, a large cluster of estimates is found at the bottom of the funnel graph and in the range of 0–0.5. A symmetric funnel plot and a near-zero association between ICTs and economic performance suggest the free of publication bias. Since Fig. 2 is skewed to the right, the funnel plot is asymmetric, showing that publication bias exists. These outcomes imply a strong tendency for better economic performance of ICTs, which is in line with the results of the vote count. That is, there is a sign that ICTs are effective tools to promote economic performance, and accommodating potential publication bias is crucial. Besides, a wide scattering at the top of the funnel graph shows the existence of heterogeneity. Thus, ICTs' effects on economic performance will likely depend on moderator variables. It is also essential to control for such effects through subsequent meta-analysis.

Though the overall positive impacts of ICTs on economic performance are shown in the funnel graphs, the effects in developing countries seem not obvious (as the estimates are randomly distributed around "zero"). It allows us to think more intensely about how a specific ICT influences economic performance in developing countries (see the 5th dimension in Table 1).

A visual inspection of funnel diagrams is a useful but subjective way to detect initial publication bias. The more rigorous precision-effect test is required (see Eq. (4)). According to the significance β_1 and β_0 in the first column of Table 3, there is publication bias in the ICTs—economic performance nexus studies, and even after correcting for the publication bias, there is still strong evidence suggesting overall genuine positive effects of ICTs on economic performance. The result confirms the visual impression of asymmetric funnel graphs.

For the following investigation by incorporating moderator factors, the results note that substantial and notable publication bias for positive effects from internet or broadband (column 2), GDP per capita (column 7), productivity (column 8), developing and developed countries (column 11), the type of data (columns 12–14), and the publication year after 2015 (column 16) could be responsible for the significant results reported in all studies (column 1). Notably, the ICTs—economic performance effects in the subgroup of internet and GDP per capita with panel data published after 2015 are greatly skewed to positive values. Conversely, the positive tendency in developed countries displayed in the vote count and funnel graph does not pass the precision-effect test.

In summary, the full story is complex and nuanced. The result is the combination of positive and negative effects of ICTs on economic performance and some specific cases cannot be overlooked.

Additionally, the trim and fill analysis is applied to test the significant publication bias items, and most of the results are robust. Taking the full sample, for example, there is no difference in heterogeneity ($p < 0.01$ in Cochrane's *Q*-test) when using the linear method (210 virtual studies are supplemented after 7 iterations), which indicates the result is statistically significant and supports the robust results.

Meta-regression analysis (MRA). The results of MRA with different specifications are presented in Table 4. The first group of independent variables involves studies conducted by different ICTs in countries with different development effects (ICD). The second category of independent variables includes other study-related characteristics (OSC). Column 3 reports all the sets of independent variables. It should be noted that this MRA is employed for 713 observations, and the dependent variable is *Fisher's z*. Thus, the coefficients of independent variables interpret the sign and significance of the effect. That is, the positive coefficient overestimates the effect and vice versa (Polák, 2017).

When exploring moderator variables, the type of ICTs in different countries of development level is first focused on and the MRA reveals some interesting results. First, the ICT variables (internet, teledensity, and ICT_index) are robustly significant and negative ($p < 0.01$), indicating the measurement of ICTs used for

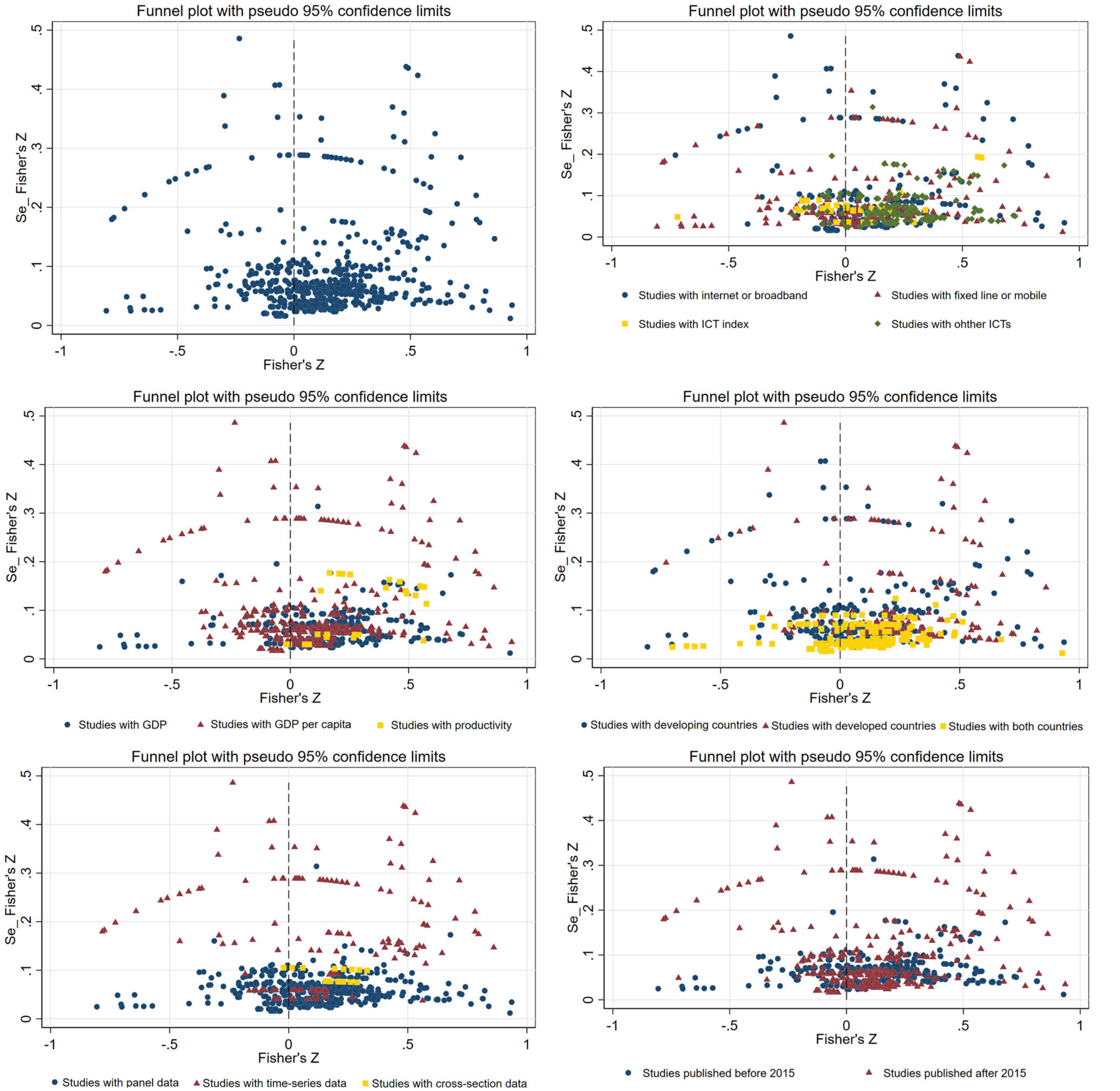

Fig. 2 Funnel graphs of ICTs for economic performance.

estimating the technological effects diminishes the reported impacts on economic performance. This is in conflict with the results of publication bias, which tends to select positive outcomes. The inconclusive fact shows that studies may underestimate the complicated influence of ICTs, and ICTs have somewhat ambiguous impacts on the economy and on the other hand, it also emphasizes the importance of detecting the negative and insignificant effects on economic performance. Second, the effects of ICTs in developed nations are significant (the coefficient of dev_ed is 0.1621, $p < 0.01$), but that is reduced in developing countries (the effects of ICTs are insignificant). It suggests that the impacts of ICTs vary among nations and differential development effects may change the way ICTs work.

For the other study-related characteristics, some independent variables are identified as statistically significant, thus affecting the results of studies. In particular, the number of observations used and the time span of the data covered in regression for estimation are found to be significant. The lower the number of observations (number) while the longer the length of time period (timespan), the higher the effect. The influences of ICTs on economic performance are weaker when the dependent variable is measured by GDP per capita (GDP_per). The result indicates that a suitable number of estimates with a relatively long timescale will generate more significant outcomes. Besides, the measurement of economic performance should be reconsidered since the contribution of ICTs may not necessarily expand the economic size of a country immediately. Lastly, panel data (panel), the most-used type of data in all selected studies, is not related to the size of the effect estimate.

The results of overall MRA (column 3 in Table 4) are similar to the above two, except for the significantly lower effects of ICTs in developing countries (dev_ing). Thus, how do ICTs impact economic performance in less-developed countries? Further validation is required.

Table 3 Precision-effect test.

	(1) All studies	(2) internet	(3) teledensity	(4) ICT_index
Slope (precision)	0.0337* (1.80)	−0.0198 (−1.04)	0.1095** (2.17)	0.0087 (0.09)
Constant (bias)	1.4786*** (3.59)	2.4779*** (5.17)	−1.082 (−1.03)	0.1316 (0.08)
Observations	713	265	229	37
Root MSE	5.671	4.490	7.640	3.524
	(5) ICT_other	**(6) GDP**	**(7) GDP_per**	**(8) prod**
Slope (precision)	0.1732*** (4.92)	0.1330*** (3.03)	−0.0180 (−1.08)	−0.0154 (−0.33)
Constant (bias)	1.0077 (1.49)	0.2784 (0.28)	1.7638*** (4.85)	3.2604*** (3.29)
Observations	182	285	398	30
Root MSE	3.522	7.334	4.078	2.918
	(9) dev_ing	**(10) dev_ed**	**(11) dev_both**	**(12) panel**
Slope (precision)	0.1034*** (2.79)	0.3995*** (10.89)	−0.0068 (−0.18)	0.0136 (0.55)
Constant (bias)	−0.1816 (−0.29)	−1.5177*** (−2.80)	2.0891* (1.74)	2.0862*** (3.47)
Observations	321	170	222	542
Root MSE	4.781	3.084	7.420	6.378
	(13) time	**(14) cross**	**(15) pub_year1**	**(16) pub_year2**
Slope (precision)	0.0602** (2.37)	0.4506*** (3.35)	0.0945** (2.19)	0.0087 (0.55)
Constant (bias)	0.5682* (1.83)	−2.9466* (−1.90)	0.7069 (0.78)	1.5966*** (4.38)
Observations	153	18	338	375
Root MSE	2.248	0.9653	6.994	4.077

T-statistics in parentheses. Dependent variable is Fisher's *z*.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Table 4 Results of MRA.

Variable	(1) ICD		(2) OSC		(3) All	
	Coefficient	*T*-statistics	Coefficient	*T*-statistics	Coefficient	*T*-statistics
internet	−0.0720***	−3.30			−0.0479*	−1.93
teledensity	−0.1321***	−5.80			−0.1307***	−4.98
ICT_index	−0.1749***	−4.35			−0.1335***	−3.11
ICT_other	-	-			-	-
dev_ing	0.0228	1.16			−0.1456***	−6.16
dev_ed	0.1621***	6.91			-	-
dev_both	-	-			−0.0855***	−3.25
GDP			-	-	-	-
GDP_per			−0.0767***	−3.96	−0.0100	−0.45
prod			0.0413	0.85	0.0642	1.39
panel			0.0249	0.93	−0.0289	−1.03
time			-	-	-	-
cross			0.1063*	1.66	−0.0104	−0.16
number			−0.0001***	−6.42	−0.0001***	−6.04
timespan			0.0063***	6.27	0.0050***	5.01
pub_year1			-	-	−0.0244	−1.20
pub_year2			0.0170	0.85	-	-
Constant	0.1600***	7.56	0.0870**	2.51	0.2992***	7.88
Observations	713		713		713	

Dependent variable is Fisher's *z*. Missing variables in each column are omitted because of collinearity.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

The results of MRA by regional variables (column 1) and different ICTs in developing countries (column 2) are shown in Table 5. ICTs' effects on economic performance are higher in European (Europe) and some developed countries (developed), but they are lower in low- and middle-income countries (lm_income). Regional variables are indeed important when exploring the impacts of ICTs, but they do not appear to be the critical determinant since some moderator effects (Asia, Africa, OECD, etc.) are not robust. For the outcomes of different ICTs in developing countries, both the use of internet (dev_int) and mobile phones (dev_mob) turned out to be meaningful. They are associated with stronger effects of ICTs, which is actually encouraging for policy-makers.

Moreover, the results of MRA with the multinomial logit form are reported in Table 6. It consists of 1082 estimates from 65 studies. The findings of ICTs—economic performance in primary studies that are insignificant are set as a base outcome. Concretely, the measurement of ICTs and the development level of countries influence the ICTs—economic performance effect. Compared with internet use alone (internet), the compound ICT index (ICT_index) is a more significant indicator with positive findings. However, the use of mobile phones and fixed-line telephones (teledensity) does not tend to exert obvious effects on economic performance. ICTs in developed countries present more robust and significant effects than in developing countries, which is confirmed by the coefficient of dev_ed and dev_both in column 1.

Regarding other study-related moderators, economic performance measured by GDP (GDP) appears to have higher odds of achieving a significant result. The probability of getting significant estimates, both positive and negative, is higher for studies with a larger size (number) and published earlier (pub_year1). Studies with a long time period of data have a tendency to get positive results, while studies with data covered by a short time span show more negative results (timespan). This outcome is predictable because the real impacts of ICTs may take effect after a period of time. The type of data does not significantly affect the results due to the insignificance of the coefficient.

By considering all the moderator variables, a relatively significant positive ICTs—economic performance effect is presented. Different ICTs in developed countries will affect economic performance for a long time, confirmed by the coefficients of ICT_index, ICT_other, dev_ed, dev_both, and timespan. The positive outcomes provide consistent evidence with the vote count and precision effect test.

Similarly, the results of MRA with the multinomial logit form by regional variables and different ICTs in developing countries are displayed in Table 7. Compared with Asian countries (*Asia*), African countries (Africa) are less likely to get positive and negative findings, while some low and middle-income countries (lm_income) are more tend to show the downside of ICTs. By contrast, ICTs' positive effects on economic performance are higher in G20 countries (G20), OECD countries (OECD), and developed countries (developed) than in Asian countries. When putting the issue on a global scale (worldwide), the results appear to be more significant, with both active and passive outcomes. Again, it is proved that different development levels of countries will influence ICTs' effects on economic performance. The beneficial or detrimental effects are varied in different samples.

Table 5 Results of MRA by regional variables and different ICTs in developing countries.

Variable	(1) Region		(2) ICTs in developing countries	
	Coefficient	*T*-statistics	Coefficient	*T*-statistics
Asia	−0.0410	−0.53		
Africa	−0.1122	−1.34		
Europe	0.1689**	2.04		
G20	-	-		
OECD	0.0132	0.16		
reg_other	−0.2109**	−2.37		
developed	0.1462*	1.81		
developing	−0.0138	−0.18		
h_income	−0.1201	−1.18		
lm_income	−0.2012**	−2.41		
worldwide	−0.1058	−1.37		
dev_int			0.1560***	3.53
dev_mob			0.1382***	3.13
dev_fix			-	-
Constant	0.1689**	2.23	−0.2833***	−0.84
Observations	713		231	

Dependent variable is Fisher's *z*. Missing variables in each column are omitted because of collinearity.
***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Table 6 Results of MRA with the multinomial logit form.

Variable	(1) IEC		(2) OSC		(3) All	
	Coefficient	*T*-statistics	Coefficient	*T*-statistics	Coefficient	*T*-statistics
The findings of ICTs—economic performance in primary studies are significantly positive						
internet (base)						
teledensity	−0.2016	−1.21			−0.2203	−1.27
ICT_index	0.6161**	2.19			0.6004**	2.07
ICT_other	1.1983***	4.78			1.1376***	3.86
dev_ing (base)						
dev_ed	0.8747***	4.33			0.9313***	4.36
dev_both	1.3591***	7.36			1.2707***	5.59
GDP (base)						
GDP_per			−0.7798***	−4.19	−0.2006	−0.94
prod			−0.5461	−1.18	−0.3597	−0.72
panel (base)						
time			−0.2360	−1.21	−0.0473	−0.23
cross			0.8583	1.53	0.3297	0.55
number			0.0005***	2.69	0.0000	0.26
timespan			0.0220***	3.54	0.0193***	2.89
pub_year1 (base)						
pub_year2			−0.3085*	−1.70	0.1096	0.55
Constant	0.0494	0.34	0.8441***	4.52	−0.2672	−1.00
The findings of ICTs—economic performance in primary studies are significantly negative						
internet (base)						
teledensity	−0.0109	−0.04			0.1844	0.62
ICT_index	0.1781	0.39			−0.1894	−0.37
ICT_other	−0.2071	−0.42			−0.2875	−0.52
dev_ing (base)						
dev_ed	−0.6086	−1.30			−0.9629	−1.97
dev_both	1.2830***	4.98			0.2061	0.61
GDP (base)						
GDP_per			−0.1543	−0.53	−0.1215	−0.37
prod			−15.7040	−0.02	−15.9392	−0.02
panel (base)						
time			0.1941	0.53	−0.0200	−0.05
cross			−14.8949	−0.01	−14.5134	−0.01
number			0.0015***	7.60	0.0013***	6.15
timespan			−0.0503***	−3.23	−0.0602***	−3.46
pub_year1 (base)						
pub_year2			−0.9500***	−3.28	−0.8032***	−2.57
Constant	−1.3783***	−6.08	−0.3954	−1.33	−0.1818	−0.41
Observations	1082		1082		1082	

Dependent variable is ICT_result.
***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Table 7 Results of MRA with the multinomial logit form by regional variables and different ICTs in developing countries.

Variable	(1) Region		(2) ICTs in developing countries	
	Coefficient	*T*-statistics	Coefficient	*T*-statistics
The findings of ICTs—economic performance in primary studies are significantly positive				
Asia (base)				
Africa	−1.0440***	−4.71		
Europe	0.2583	0.90		
G20	2.8304***	4.65		
OECD	1.2619***	3.21		
reg_other	−0.7024*	−1.66		
developed	1.9367***	3.94		
developing	−0.0423	−0.17		
h_income	0.4634	0.77		
lm_income	−0.3943	−0.93		
worldwide	0.8213***	3.18		
dev_int (base)				
dev_mob			0.5986**	2.37
dev_fix			0.0168	0.06
Constant	0.5482***	3.46	−0.2400	−1.38
The findings of ICTs—economic performance in primary studies are significantly negative				
Asia (base)				
Africa	−1.0093**	−1.98		
Europe	−1.4735	−1.38		
G20	−12.6654	−0.02		
OECD	0.9343	1.37		
reg_other	1.3034**	2.42		
developed	−13.4523	−0.02		
developing	0.2289	0.47		
h_income	1.0521	1.14		
lm_income	2.2562***	4.60		
worldwide	2.1507***	5.34		
dev_int (base)				
dev_mob			0.1233	0.27
dev_fix			1.0369***	2.61
Constant	−1.7452***	−5.34	−1.7525***	−5.83
Observations	1082		384	

Dependent variable is ICT_result.
***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Analyzing the effects of different ICTs in developing countries, interesting findings are got. Compared with employing the internet, using mobile phones (dev_mob) is likely to positively affect the country's economy, and using fixed-line telephones (dev_fix) tends to diminish the economic return of ICTs. The wireless technologies and mobile telecommunications are easier to install and use, and to a certain extent, they are fairer to all kinds of users, both rich and poor. It can be said that in the future, more convenient and faster ICTs will make profound impacts on less-developed economies and the effects of old and outdated technology will gradually decrease or even disappear completely.

Discussion

It is worthwhile to evaluate ICTs' genuine effects on the economic performance of countries by applying the meta-analysis. This topic necessitates ongoing scrutiny and evaluation in light of current research advancements. The study expanded the sample size as well as included the latest research. The central finding indicates that the extant literature verifies ICTs' contributions to economic growth, but there remains heterogeneity between studies. Clarifying the similarities and differences in previous research can help identify directions for future studies in this field.

First, there is a growing body of research that has quantitatively analyzed the effects of ICTs on economic performance at the country level. The publication bias exists and it is essential to correct such selection bias. After detecting and accommodating potential publication bias, the results turn out that ICTs have indeed contributed positively to economic performance, at least on average. Nonetheless, the majority of research has focused on illustrating this phenomenon without delving into a comprehensive theoretical analysis of the mechanisms through which ICTs influence economic growth. The exploration of the causal relationship between ICTs and economic performance is not the sole objective; rather, it is imperative for scholars to conduct a more profound investigation into the underlying reasons, modalities, and duration of the direct and indirect effects of ICTs on economic performance.

Second, in this study, the form of data has little effect on the results of estimates, but the size and time span of data have an impact. In previous studies, the magnitude of ICTs' effects on economic performance is significant when the number of samples reaches a reasonable size, meanwhile, ICTs produce sizeable effects when they arrive at critical masses. Wu et al. (2021) point out that internet makes the economic disparities distinct between high-penetration cities and low-penetration cities. Besides, the influences of ICTs change over time (Kumar et al., 2015). Given the diverse long-term, medium-term, and short-term impacts of ICTs, there is a need for more robust analyses that utilize data with distinct characteristics across various time scales. This approach is essential to establish a compelling and solid evidence base for the contribution of ICTs to economic performance.

Third, the measurement of ICTs and economic performance is diverse. For ICTs, the normal practice is examining the influences of fixed-line telephones, mobile phones, and the internet on growth. As ICTs continue to evolve at a rapid pace, it is imperative for researchers to adopt a proactive approach in examining the impacts of emerging ICTs, including artificial intelligence, 5G, and big data. These technologies offer the potential for conducting comparative experiments that can yield valuable insights for subsequent research. In assessing economic performance, traditional macroeconomic indicators such as GDP and productivity are commonly employed. However, given that economic performance is a multifaceted concept, scholars are encouraged to explore innovative dimensions, such as the influence of ICTs on the new economy, financial development, and national innovation. By doing so, they can contribute to and enrich the existing body of research with more comprehensive findings.

Fourth, whether developed or developing countries tend to benefit more from ICTs is a heated topic. Consistent with the extant studies, the study confirms the fact that ICTs differentially affect economic performance in developed and less-developed nations. The result is likely to validate the positive effects of ICTs in developed countries while developing countries gain less economic benefit from ICTs. The primary rationale appears to be that developed nations possess a stronger developmental foundation, enabling them to harness greater innovation opportunities from advancements in ICTs. This, in turn, fosters the upgrading of industrial structures and sustains economic growth. However, the long-run positive impacts remain ambiguous, it is rational to question whether the active role of ICTs in developed countries will gradually diminish and whether the leapfrogging role of ICTs in developing countries has been overstated. Moreover, it seems that mobile technology is more effective than fixed technology (Chavula, 2012; Lee et al., 2012). Studying how more convenient, faster, and lower-cost ICTs help countries, especially underdeveloped or low- and middle-income countries, to improve the economy, will be a research tendency in the future.

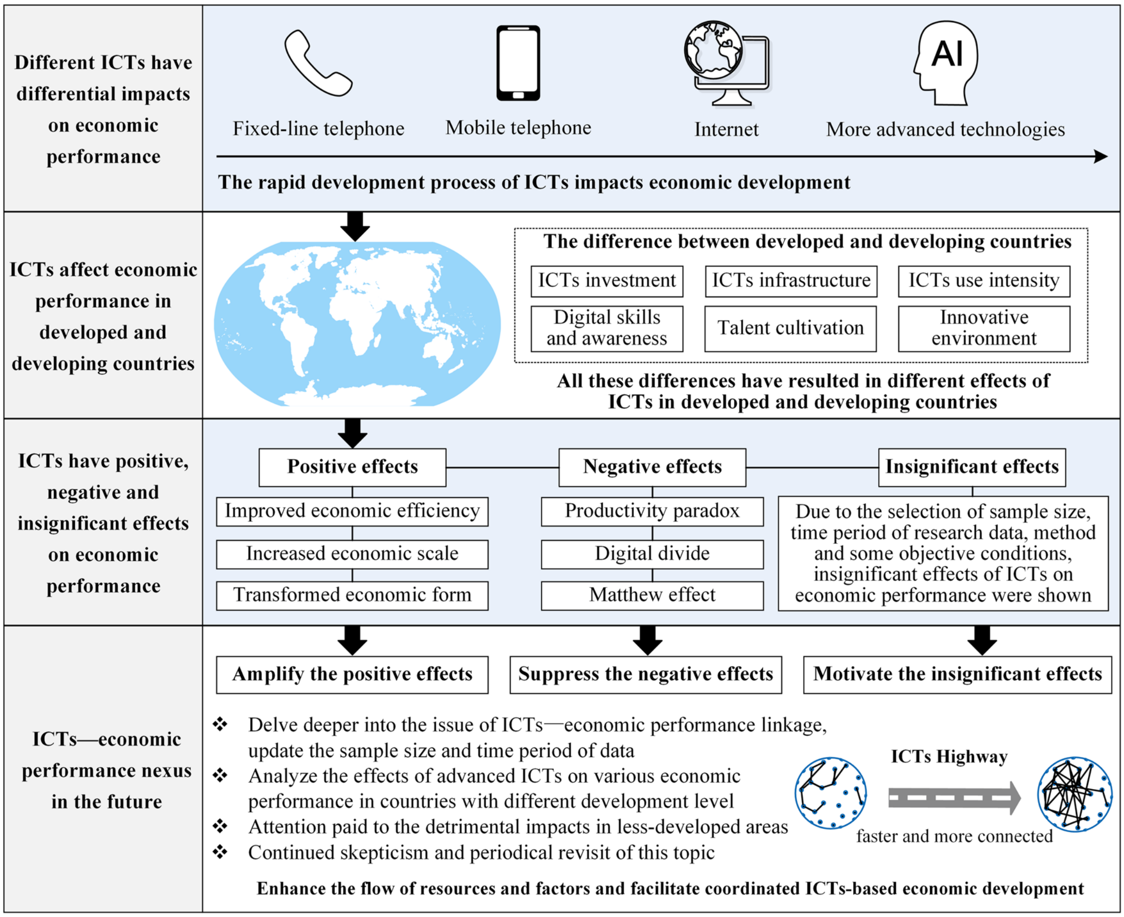

Fig. 3 Analysis of the relationship between ICTs and economic performance.

Fifth, the study is conducted by using categorical results (positive, negative, or insignificant results) and Fisher's z-transformation value as the dependent variable respectively, and the outcomes of the two are robust. In general, the positive effects of ICTs on economic performance are more obvious, but the negative and insignificant impacts also provide valuable insights into the study. Scholars should think carefully about how to correctly measure such potential effects. The theory of productivity paradox or digital divide alone is not enough to support the complicated and varied influences of ICTs. The maturity of ICTs' development, the degree of the application of ICTs, the subjective awareness of using ICTs, and the objective basic conditions of the external environment should be taken into account holistically. Therefore, to better understand the effects of ICTs, continued skepticism is needed, instructing scholars to revisit and update the topic periodically.

Further, the discussion of the effects of ICTs is becoming increasingly popular for published studies. The relationship between ICTs and economic performance is also becoming increasingly important and requires reliable empirical research. Figure 3 displays the ICTs—economic performance nexus and the future directions.

Conclusions

The study explores the effects of ICTs on economic performance at the country level by using a meta-analysis with 1082 estimates from 65 studies, which is a topic that requires frequent reflection and review. After investigating the vote count, funnel plot, precision-effect test, and meta-regression analysis, it finds clear evidence to support that ICTs are beneficial for economic development and that publication bias exists among studies. Furthermore, different ICTs have varied economic impacts on different countries, and overall, developed countries benefit more from ICTs, while mobile technology has more potential for economic growth. Additionally, the type of data has little influence on research findings, and more attention should be paid to the time span of the data covered. One of the limitations of the meta-analysis in the study is that only a limited number of possible variables are employed to detect research differences, and as a result, the characteristics of different studies cannot be fully captured.

In conclusion, this study highlights the positive role of ICTs, meanwhile, the negative effects on economic performance cannot be ignored, especially for developing countries. It provides a reference for policy-makers pursuing ICTs-based economic development as well as raises study avenues for the future.

Data availability

The datasets of selected studies are provided as supplementary files. Other datasets generated during the current study are available from the corresponding author on reasonable request.

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The authors declare no competing interests.

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This article does not contain any studies with human participants performed by any of the authors.

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Additional information

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