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Backwardness Advantage and Economic Growth in the Information Age: A Cross-Country Empirical Study

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Abstract

This paper seeks to gain insights into whether developing countries benefit more from the backwardness advantage for economic growth in the Information Age. The paper examines this concern through three complementary approaches. First, it derives theoretical grounds from the existing economic models to support the hypothesis that the internet, inter alia, enables developing countries to reap greater growth gains from technology acquisition and catch-up. Second, the paper uses descriptive evidence to show that the growth landscape has indeed shifted decisively in favor of developing countries in the Internet Age in comparison to the pre-internet period. Third, using rigorous econometric techniques with data of 163 countries over a 20-year period, 1996-2016, the paper evidences that developing countries on average reap significantly greater growth gains from internet adoption in comparison to the average advanced country. The paper discusses policy implications from the paper's findings.

Keywords: backwardness advantage; developing countries; internet; technology catch-up; GMM.

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1. Introduction

Gerschenkron (1962) coined the term "backwardness" advantage, with which he argues that developing countries have an advantage over developed nations because they can quickly and less riskily adopt technologies, methods of production, and management techniques that have been developed in advanced countries. Furthermore, the more distant a country is from the world's technology frontiers, the greater the potential benefits it can reap from this advantage.

Although the backwardness advantage is a powerful economic concept that has been theoretically explained by influential studies[1], empirical evidence supporting it remains scant. A possible reason for this deficient support is the lack of adequate data for conducting rigorous investigations to examine this hypothesis.

The Information and Communication Technology (ICT) revolution, especially the rapid penetration of the internet and mobile technologies across nations and sectors since the 1990s, has enabled countries and firms to considerably enhance their connectivity with the world, accessibility to global knowledge, and learning capabilities, which have potentials effects on global economic growth (Jorgenson and Vu, 2005, 2016).For developing countries, this progress has indeed been a paradigm shift. This leapfrog change enables developing countries to overcome the critical, previously unsurmountable problems thathave hindered most developing countries from exploiting their backwardness advantage. These problems range from shortages of information and poverty of knowledge to disconnection with advanced countries and the prohibitive costs of communication (Tchamyou, Erreygers and Cassimon, 2019).

The rapid penetration of the internet and mobile technology, to a certain extent, provides valuable insights into the dynamism of developing countries in embracing the ICT revolution to overcome the problems that have hampered them from exploiting their backwardness advantage. However, empirical studies to examine the growth effects of this paradigm shift on developing countries remain limited, probably due to two possible reasons. First, the main

[1] For example, see Nelson and Phelps (1966), Krugman(1979), and Grossman and Helpman (1991).

objective of most studies is to detect the overall effect of ICT on growth across nations,[2]without looking deeper into whether the effect is stronger for developing countries. Second, a few studies that inspect this issue do not reveal significant evidence of the greater growth gains that developing countries are expected to reap from ICT adoption. For example, Niebel (2018), who investigates whether the gains from investments in ICT differ between three groups of economies[3], developing, emerging, and developed, does not detect any statistically significant differences among them in the growth effect of ICT. With this finding, the author calls into question the expectation that developing countries are 'leapfrogging' through ICT. This view is supported by Papaioannou and Dimelis (2007) and Dedrick et al. (2013), who find that productivity gains from investments in ICT assets are significant in both developed and developing countries but that these gains are not different between the two groups. It follows that the research aims to assess the whether the findings of Papaioannou and Dimelis (2007) and Dedrick et al. (2013) and Niebel (2018) withstand empirical scrutiny, using more countries and updated data.

Moreover, the earlier studies that use data from the initial stage of the ICT revolution are even more skeptical about the growth effects of ICT in developing countries. For example, Bell and Pavitt (1993), Dewan and Kraemer (2000), Pohjola (2001), Lee et al. (2005), and Park et al. (2007) find that the ICT-growth link is positive and significant only for developed countries. According to these authors, undeveloped human capital and poor telecommunications infrastructure are likely the main factors that hinder developing countries from reaping ICT-enabled growth effects.

As the ICT revolution, particularly the internet has rapidly penetrated across nations and reached substantial rates of penetration even in low-income ones, developing countries have undertaken leapfrog improvements in their accessibility to frontier knowledge and learning capabilities. As a result, it is plausible that ICT penetration, for which internet adoption is a key

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[2]For example, see which are mostly focus on developed countries *inter alia*, Jorgenson and Stiroh (2000), Oliner and Sichel (2002), Inklaar, O'Mahony, and Timmer (2005), Inklaar, Van Ark, O'Mahony, and Timmer (2008). For a recent comprehensive survey of literature on the growth effect of ICT see Vu, Hanafizadeh, and Bohlin (2020).

[3]The study, examining a sample of 59 countries for the period 1995–2010, finds a strong link between ICT penetration and growth for the overall sample.

indicator, has a significant effect on growth in developing countries, especially through enhancing their capabilities to exploit the backwardness advantage. Indeed, some previous studies have found significant evidence on the internet-growth link at the firm level. For example, Paunov and Rollo (2016), investigating the firm-level data from 117 countries over 2006-2011, show that firms with adequate absorptive capabilities reap significant productivity gains from Internet-enabled knowledge access. Similarly, Fernandes et al. (2019), examining China's firm-level data for 1999-2017, find that the Internet not only boosts trade, but also enhances overall firm performance.

The main research question addressed by this paper is whether internet adoption has enabled developing countries to more effectively exploit the backwardness advantage to achieve higher economic growth. The underlying research question is consistent with the stated aim of assessing whether the findings of Niebel (2018) as well as of Papaioannou and Dimelis (2007) and Dedrick et al. (2013) have contemporary relevance when more countries and contemporary data are taken on board. It is important to note that according to Niebel (2018): "*The regressions for the subsamples of developing, emerging and developed countries do not reveal statistically significant differences in the output elasticity of ICT between these three groups of countries. Thus, the results indicate that developing and emerging countries are not gaining more from investments in ICT than developed economies, calling into question the argument that these countries are 'leapfrogging' through ICT*" (p. 197).

Revisiting Niebel (2018) in a different context is both relevant to scholars and policy makers for at least two reasons. On the scholarly front, as more data become available in time (i.e. recent years) and space (i.e. more countries), it is worthwhile for researchers to assess if the findings of studies based on less contemporary frameworks withstand empirical scrutiny. Doing so helps in confirming and refuting tendencies in contributions to knowledge which can change across time. Second, it is important for policy makers to be aware of factors that facilitate the economic development catch-up process because these factors are, *inter alia*, taken into account in decision making processes surrounding national and international measures of reducing cross-country disparities in economic development across the world. Hence, given the potential of ICT penetration in developing countries on the one hand and the findings of Niebel

(2018) which question whether developing countries are “leapfrogging” through ICT on the other hand, it is relevant to provide policy makers with another perspective based on recent data and more countries including also the least developed ones. The empirical study, therefore, will focus on detecting whether developing countries can reap a greater growth gain from internet adoption in comparison to developed nations. In contrast to previous studies by Papaioannou and Dimelis (2007), Dedrick et al. (2013) and Niebel (2018) which rely on samples consisting of a total of less than 60 countries with data updated only to 2010, this paper examines an exhaustive sample of 163 countries with a time span of data updated to 2016.

It is worthwhile to articulate that the focus of this research also steers clear of the extant contemporary technological forecasting and technological spillovers literature, which has largely been oriented towards, *inter alia*: issues surrounding business prospects’ forecasting (Amankwah-Amoah, Osabutey and Egbetokun, 2018); the effect of technological externalities on small and medium size enterprises (Del Giudice, Scuotto, Garcia-Perez and Petruzzelli, 2019); the relevance of inter-sectoral spillovers in knowledge pertaining to innovations that are technology-oriented (Stephan, Bening, Schmidt, Schwarz and Hoffmann, 2019); technologies in learning and diffusion of knowledge within global and local spheres (Zhang, Bauer, Yin and Xie, 2020); the importance of spillovers in knowledge in the production of sustainable energy (Miremadi, Saboohi and Arasti, 2019); spillovers from technology in patent and trade markets (Cai, Sarpong, Tangand Zhao, 2020) and improving information technology for sustainable and inclusive (Asongu and le Roux, 2017) development outcomes. The positioning of the current research is closest to the last strand of the attendant studies because the focus of the research is on how information technology can enable cross-country catch-up in economic development. Accordingly, in the light of theoretical underpinnings surrounding catch-up in an outcome variable, such catch-up is only feasible when there are cross-country disparities in factors (i.e. contained in the conditioning information set) that are exogenous to the outcome variable (Narayan, Mishra & Narayan, 2011). It follows that the rate at which technology is increasing in sampled countries determines cross-country catch-up tendencies, which is consistency with the last strand of enhancing information technology for development outcomes (e.g. Asongu & le Roux, 2017).

The remainder of this paper is structured as follows. Section 2presents theoretical grounds derived from existing economic models that support the hypothesis that internet adoption, *inter alia* (i.e. other adopted elements in the conditioning information set),enables developing countries to reap greater growth gains by enhancing their backwardness advantage. Section 3 demonstrates the descriptive evidence that developing countries over the past two decades, on average, significantly improved their economic performance in comparison to developed nations. In Sections 4 and 5, rigorous empirical estimations are conducted to test the hypothesis using the data of 163 countries over the period from 1996 to 2016. Section 4 presents the econometric specification, data, and estimation techniques. The examination aims to address, to the extent possible, the potential problems of omitted variable bias and simultaneity, emphasizing the control of country-fixed effects and employing the generalized method of moments (GMM) approach. Section 5 presents the estimation results. Section 6 concludes the paper.

2. The internet as a stimulator of growth: Some theoretical grounds

This section relies on existing economic models to derive the theoretical grounds that support the hypothesis that internet adoption enables developing countries to reap greater growth gains by exploiting their backwardness advantage. The three models to be examined include “technological catch-up”, “leader-follower”, and “appropriate technology”, which provide consistent and complementary views of the power of knowledge acquisition in economic catch-up.

2.1. The technological catch-up model

Rogers (2004: 578) presents a simple model of technological catch-up introduced by Nelson and Phelps (1966) that can help shed light on the effect of internet penetration on growth. The model describes the growth of technology in a country as follows:

$$\frac{\dot{A}(t)}{A(t)} = \varphi(.)\left[\frac{T - A(t)}{A(t)}\right] = \varphi(.)\{[T/A(t)] - 1\} \quad (1)$$

where $A(t)$is the country's technology level at time t and$\dot{A}(t)/A(t)$is its growth rate, T is the world practice technology, and $\varphi$is a function representing absorptive capability.

The model, as such, indicates that the growth rate of technology in a country$g_A = \dot{A}(t)/A(t)$ is determined by two characteristics: its absorptive capabilityφ and the technology gap between it and the world frontier$\{[T/A(t)] - 1\}$.

This model supports the backwardness advantage thesis stated by Gerschenkron (1962) and in more contemporary literature on technology spillovers to developing countries (Stephan et al., 2019; Zhang et al., 2020). According to the thesis, developing countries have an advantage over advanced nations because they can adopt technologies and management methods that have been developed in advanced nations.

Regarding the absorptive capability φ, Rogers (2004) articulates three major elements. The first is accessibility to overseas technology, which takes into account the country's business, educational, and social linkages with international markets, suppliers, and investors. The second element is learning ability, which particularly emphasizes the ability to understand, communicate, and internalize a new technology. The final element is related to the macro factors that encourage or hinder the adoption of new technologies, which range from government incentives to entrepreneurship, from sociopolitical stability to business environment.

Eq (1) indicates that a lower$A(t)$, which means a lower$A(t)/T$ ratio, implies a greater g_A, controlling for $\varphi(.)$. That is, if a country is further away from the world technology frontier, it has a greater potential to grow faster by narrowing its technological gap, while sustaining or improving its absorptive capabilities. The paragraphs below will explain why the internet enhances developing countries' backwardness advantage and facilitates their efforts to exploit it.

Solving the differential equation described in Eq (1) yields a family of solutions, including the following[4]:

$$A(t) = T - \theta e^{-\varphi t} \qquad (2)$$

where θ ($0 < \theta < T$) is a constant.

It is easy to verify that the solution specified in Eq (2) is a valid solution of the differential equation expressed in Eq (1) and that $0 < A(t) < T$.

Two insights can be drawn from Eq (2). First, $\partial A/\partial\varphi = \theta t . e^{-\varphi t} > 0$, which means that enhancing a country's absorptive capability φ will increase its technology level A. Second, $\partial A/\partial T = 1 > 0$, which means that expanding the world's available technology stock has a positive effect on A. These insights suggest that the internet can elevate the technology level A through two channels. On the one hand, it enhances the country's absorptive capability φ, which includes access to foreign technology, the learning ability of businesses, and the set of factors influencing the firm-level adoption of technology. On the other hand, it expands the stock of world technologies T that the country can practically find and acquire. It is plausible to conjecture that the effect of internet penetration on $\Delta T/T$is larger for a typical developing country than for a typical developed nation because, without the internet, the former suffers from more severe problems related to access to information, connectivity, and communication. As pointed out by Haussmann and Rodrik (2003), the neoclassical model's assumption that the knowledge of all extant goods is common and accessible by all countries is not plausible. Furthermore, the authors echo Nelson (2000), Evenson and Westphal (1995), and Lall (2000) when saying that much of this knowledge is ''tacit'', which means that it requires intensive communication and robust exchanges to become imitable.

At the same time, the effects of internet use on the absorptive capability $\varphi$of a typical developing country are likely substantial in accordance with the three major elements specified by Roger, which include the accessibility to global knowledge, the learning ability of businesses and workers, and an enabling environment for technology adoption as presented above.

[4]To simplify the exposition, we assume that φ and T do not depend on t. Considering φ as T functions of t results in a more complex solution but yields the same insights.

The discussion above suggests that internet adoption enables developing countries to enhance their capabilities to exploit their backwardness advantage. This internet-enhanced catch-up effect, therefore, is expected to enable developing countries to grow faster than developed ones during the Information Age, all else being equal.

2.2. The leader-follower model

Kuznets (1966) argues that increasing the "transnational stock of knowledge" facilitates economic growth in each nation because "no matter where these innovations emerge… the economic growth of any given nation depends upon their adoption," (p. 286).

Barro and Sala-i-Martin (1995, Chapters 6, 8; 1997) present a model that can help explain how innovation and technology imitation affect the rate of economic growth. In this model, the growth of the leader economy (economy 1) is driven by its innovations, while the growth of the follower economy (economy 2) depends on its imitation of the innovations that have been made in the leader economy. From the model developed by Barro and Sala-i-Martin (1995, p. 268-273), the growth rate γ_1 of the leader economy can be expressed as follows:

$$\gamma_1 = (1/\theta).\left[(L_1/\eta).\left(\frac{1-\alpha}{\alpha}\right).(A_1)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)} - \rho\right] \quad (3)$$

where $\theta > 0$ and $\rho > 0$are parameters related to the utility function of households;$0 < \alpha < 1$is the elasticity of the marginal product of intermediate goods in the production function (the model assumes that the parameters θ, ρ, and α are similar for the two economies);$A_1 > 0$represents the productivity level of country 1, which is determined by its level of technology and quality of governance;$L_1$is the labor endowment; and η is the unit cost of inventing a new variety of intermediate goods.

At the same time, the growth rate $\gamma_2$of the follower economy can be expressed in an equation similar to Eq (3). Furthermore, the growth rate γ_2 of the follower economy can be linked to the growth rate γ_1 of the leader economy as follows (p. 273)

$$\gamma_2 \approx \gamma_1 - \mu.log\left[\frac{N_2/N_1}{(N_2/N_1)^*}\right] \quad (4)$$

where $\mu > 0$ is a positive parameter that determines the speed of convergence, N_1 is the number of varieties of intermediate products that have been discovered in the leader economy, $N_2 (< N_1)$ is the number of varieties that the follower economy has adopted, and $0 < (N_2/N_1)^* \leq 1$ is the ratio when the two countries have reached their steady states, in which $N_2/N_1 = (N_2/N_1)^*$ and hence $\gamma_2 = \gamma_1$.

This model can be slightly modified to explain how internet adoption can boost economic growth in both leader and follower economies. In their model, Barro and Sala-i-Martin assume that the follower has good knowledge of all N_1 varieties of intermediate products that have been discovered in the leader economy. However, this is not the case in the real world, in which businesses in the follower economy have limited access to information and a limited capability to communicate with foreign suppliers to understand which varieties have been viable in the leader economy. Therefore, the actual number of varieties introduced in the leader economy that businesses in the follower economy can practically find to explore imitation possibilities is N_1^A, which is smaller than N_1.

Applying the leader-follower model to the real world, it is plausible to assume that a typical developed country represents the leader economy, while a typical developing country embodies the follower economy pattern. As such, the internet has a positive effect on growth in developed and developing countries, as follows.

Developed countries

The internet positively affects the growth rate γ_1 expressed in Eq (3) for a typical developed countryas follows:

- Reducing the cost of invention ω through internet-enabled operational improvements, including better access to global knowledge, lower costs of learning, more effective communication and coordination.

- Enlarging the labor endowment L_1, which is the product of the total labor force and its average level of knowledge (e_1). By making knowledge more readily accessible to ordinary people and facilitating their learning, the internet raises e_1. In addition, the internet also helps enlarge the labor force by enabling people to work part-time, anywhere, and anytime.
- Elevating the level of productivity A_1. The internet makes this elevation possible by enhancing transparency and fostering learning, knowledge sharing, performance benchmarking, and adoption of best practices, which strengthen the country's technology competence and the governance quality.

Developing countries

The internet's positive effects on growth in developing countries can be seen from two angles. On the one hand, it boosts their imitation activities. Similar to what was presented above for innovation activities in developed countries; the internet fosters technology acquisition in developing countries through three transmission channels:[5] lowering the cost of imitationυ; raising the labor endowmentL_2; and elevating the level of technologyA_2. On the other hand, it enhances the developing countries' backwardness advantage, as shown in Eq (5) below. Note that Eq (5) is modified from Eq (4) by replacing theoretical N_2/N_1 with actual N_2/N_1^A.

$$\gamma_2 \approx \gamma_1 + \left\{-\mu. log\left[\frac{N_2/N_1^A}{(N_2/N_1^A)^*}\right]\right\} \quad (5)$$

As implied by Eq (5), the internet can accelerate γ_2 through two channels: boosting growth in the leader economy(γ_1) and enlarging N_1^A– the actual number of varieties introduced in the leader economy that firms in the follower economy can find to study for imitation. Note that the ratio $N_2/N_1^A$is always below its steady stage level $(N_2/N_1^A)^*$, which means that the second

[5] The growth rate of the follower country is expressed as (Barro and Sala-I-Martin, 1995: 270):
$\gamma_2 = (1/\theta).\left[(L_2/\upsilon).\left(\frac{1-\alpha}{\alpha}\right).(A_2)^{1/(1-\alpha)}\alpha^{2/(1-\alpha)} - \rho\right]$.

term of Eq (5), $\left\{-\mu . log\left[\frac{N_2/N_1^A}{(N_2/N_1^A)^*}\right]\right\}$ takes a positive value. Enlarging N_1^A therefore increases the absolute value of $log\left[\frac{N_2/N_1^A}{(N_2/N_1^A)^*}\right]$ and, hence,raises γ_2.[6]

2.3. The appropriate technology model

Basu and Weil (1998) present a model of growth and technology transfer, which implies that technology improvements will diffuse slowly, even if there are no barriers to knowledge transfer and no adoption costs. This model and underlying intuition, as apparent in the contemporary information technology for economic growth literature (Abor, Amidu and Issahaku, 2018; Miremadi et al., 2019; Cai et al., 2020), can also be used to provide theoretical grounds for supporting the hypothesis that the internet is a stimulator of growth and that its effect tends to be greater for developing countries. As modeled by the authors (p.8), the relationship between the growth rate g of a country and its technology level$A(k,t)$isas follows:

$$A(k,t) = \left(1 - e^{-\beta\gamma/g}\right). A^*(k) \quad (6)$$

where $\beta > 0$ and $\gamma > 0$ are the model's parameters, and$A^*(k)$ is the technology level at the steady state.

From Eq (6), the economic growth g can be expressed as

$$g = \frac{\beta\gamma}{-\ln[1 - A(k,t)/A^*(k)]} \quad (7)$$

Note that $A(k,t)/A^*(k)$ takes a value between 0 and 1, the denominator in Eq (7) $\{-\ln[1 - A(k,t)/A^*(k)]\}$ is positive and its magnitude decreases as the technology ratio $A(k,t)/A^*(k)$declines. It is plausible that internet penetration enhances both the country's accessibility to global knowledge and its absorptive capability, which would raise the steady-state technology level $A^*(k)$. This enhancement tends to be larger for a developing country

[6] To illustrate, consider the following simple hypothetical example: N_2/N_1^A=0.4; $(N_2/N_1^A)^*$=0.8; μ=2.5%; and the internet helps enlarge N_1^A such that the current N_2/N_1^A declines from 0.5 to 0.3. This effect is translated into a growth gain of -2.5%*[ln(0.3/0.8) - [ln(0.5/0.8)] = +1.3%.

than for a developed nation. Along the same lines, Eq (7) indicates that internet adoption fosters economic growth, and this acceleration is stronger for developing countries than for developed ones.[7]

Besides, some other important studies also suggest valuable insights into this analysis. Acemoglu, Aghion, Lelarge, Van Reenen and Zilibotti (2007) show that reliance on technology acquisition may no longer be the best strategy for developing countries as they approach closer to the world technology frontier. At the same time, Galor and Weil (2000) and Galor and Moav (2004) demonstrate that while growth in a country depends more heavily on capital accumulation in its early stage of development, it will be more driven by human capital accumulation in a later stage. That is, the effect of internet adoption on growth in developing countries is likely stronger for less developed countries through fostering capital accumulation and for more developed countries through human capital accumulation.

Overall, all three theoretical models presented in this section support the hypothesis that developing countries have the potential to achieve greater growth gains from Internet adoption. Sections 3-5 that follow will test this hypothesis with different approaches. While Section 3 conducts only a simple reality check, Sections 4 and 5 employ rigorous econometric techniques to tease out empirical evidence.

3. The backwardness advantage as a booster of economic growth in the information age: a reality check

The 20-year period from 1996 to 2016, which witnessed the rapid penetration of the internet across nations[8]can be used to conduct a quick reality check to see whether there was a notable

[7]As an illustrative example, assume that$A(k,t)/A^{*}(k)$ declines from 0.6 to 0.5, and the denominator in Eq (7) decreases from {-ln(1-0.6)}= 0.92 to {-ln(1-0.5)}=0.69. As a result, the growth rate g will accelerate from $\beta\gamma/0.92 = 1.09\ \beta\gamma$ to $1.44\ \beta\gamma$. Note that $\beta\gamma > 0$.

[8] In fact, median internet penetration of the developing countries soared by more than 600 times, from 0.07% in 1996 to 46.3% in 2016. This pattern was observed for most large economies. For example, China (4,066 times, from 0.013% to 53.2%), India (638 times, from 0.046% to 29.5%), Indonesia (450 times, from 0.057% to 25.5%), Mexico (297 times, from 0.20% to 59.5%), Brazil (135 times, from 0.45% to 60.9%), and Vietnam (350,000 times, from 0.000% to 46.5%). For comparisons, median internet penetration of the developed countries rose by about 20 times, from 4.5% in 1996 to 88.4% in 2016 (Data source: WDI, 2019).

growth acceleration pattern in this period and how developing countries performed in comparison to developed ones. It should be noted that growth acceleration during this period,if observed, would be driven by many factors other than internet use. These factors can range from the accelerated pace of globalization and human capital development to technology progress and new waves of market-oriented policy reforms in emerging economies. Although one should not attribute this growth acceleration solely to internet use, the internet has undoubtedly had a positive effect on all these factors. At the same time, there are emerging factors that could cause growth slowdown in developed countries, which include the steady state, population ageing, and competition from emerging economies. That is, the growth acceleration, on average, is expected to be greater for developing countries than for developed ones.

For benchmarks, our reality check compares the economic performance between the invested period of 1996-2016 and its previous equivalent period (1976-1996). To make comparisons meaningful, the exercise is focused on a subsample of 115 countries for which data is available for both the 1976-1996 and 1996-2016 periods. These 115 countries can be divided into two groups – "developing" (93 developing countries) and "developed" (22 developed economies).[9]

Our reality check exercise examines whether the reality supports the following three hypotheses:

Hypothesis #1: Economic growth rates of developing countries, on average and in distributions, significantly improved from 1976-1996 to 1996-2016.

Hypothesis #2: The growth acceleration from 1976-1996 to 1996-2016 is more notable for the developing group than for the developed one.

[9] We use the classification developed countries defined by UN (1990), which was established before the emergence of the internet.

Hypothesis #3: The growth landscape for the developing group vis-a-vis the developed group looks more encouraging in 1996-2016 (the internet period)than in 1976-1996 (the non-internet period).

It is relevant to note that while the third testable hypothesis underpins the importance of internet in explaining cross-country differences in economic growth during the period 1996-2006, the modeling is such that the internet is not exclusively responsible for cross-country differences in economic growth. This is essentially because, in a real world, economic growth is not exclusively contingent on internet penetration, but as well depends on other macroeconomic factors that should be taken on board. Hence, the modeling approach adopted in this study that incorporates this reality is the conditional convergence approach within the framework of conditional convergence GMM modeling. While in unconditional convergence modeling, only the lagged dependent variable is used as the independent variable of interest, in conditional convergence modeling, other elements in the conditioning information set (i.e. control variables) are involved in the regression exercise, such that cross-country changes in the outcome variable are contingent on cross-country changes in all elements in the conditioning information set.It follows that the assessment of Hypothesis 3 in the empirical analysis will consists of establishing that, internet penetration is a significant contributor to cross-country differences in economic growth.[10]

The results from Table 1 show that the average GDP per capita growth rate of the developing group accelerated by 1.3% points, from 0.7% in 1976-1996 to 2.0% in 1996-2016, while its standard deviation narrowed by 1.1% points, from 2.9% to 1.8%. At the same time, the average growth rate of the developed group decelerated by 0.6% points, from 2.0% to 1.4%, while its standard deviation was unchanged at 0.7% but its (Min—Max) range widened, from (0.8%--

10The intuition is sound and consistent with theoretical underpinnings. Accordingly, the intuition of convergence is that cross-country catch-up in the outcome variable is possible if sampled countries exhibit cross-country differences in the elements of the conditioning information set (Asongu and Nwachuwku, 2016). Hence, in the light of this definition of conditional catch-up, if the sampled countries differ in terms of internet penetration and other control variables, then catch-up is theoretically possible. This should practically be expected because while internet penetration has reached saturation levels in developed countries, developing countries are still characterized by some high penetration potential

3.8%) to (0.2%--4.1%). These findings support Hypothesis #1 and Hypothesis #2. In addition, the contrasting patterns observed for the developing and developed groups on growth variation, which is narrowing for developing countries and widening for developed ones, is worth noting. This pattern suggests that, while the internet has improved the level playing field for developing countries to exploit their backwardness advantage, it has enlarged the divergence in the developed group on economic performance.

Table 1: Average GDP per capita growth rate by group: 1996-2016 vs. 1976-1996

Group	N	Mean	Std. Dev.	Min	Max
Developing countries					
1976-1996 (a1)	93	0.7%	2.9%	-12.7%	8.1%
1996-2016 (a2)	93	2.0%	1.8%	-2.0%	8.5%
Change (a2-a1)	***0***	***1.3%***	***-1.1%***	***10.7%***	***0.4%***
Developed countries					
1976-1996 (b1)	22	2.0%	0.7%	0.8%	3.8%
1996-2016 (b2)	22	1.4%	0.7%	0.2%	4.1%
Change (b2-b1)	***0***	***-0.6%***	***0.0%***	***-0.6%***	***0.3%***

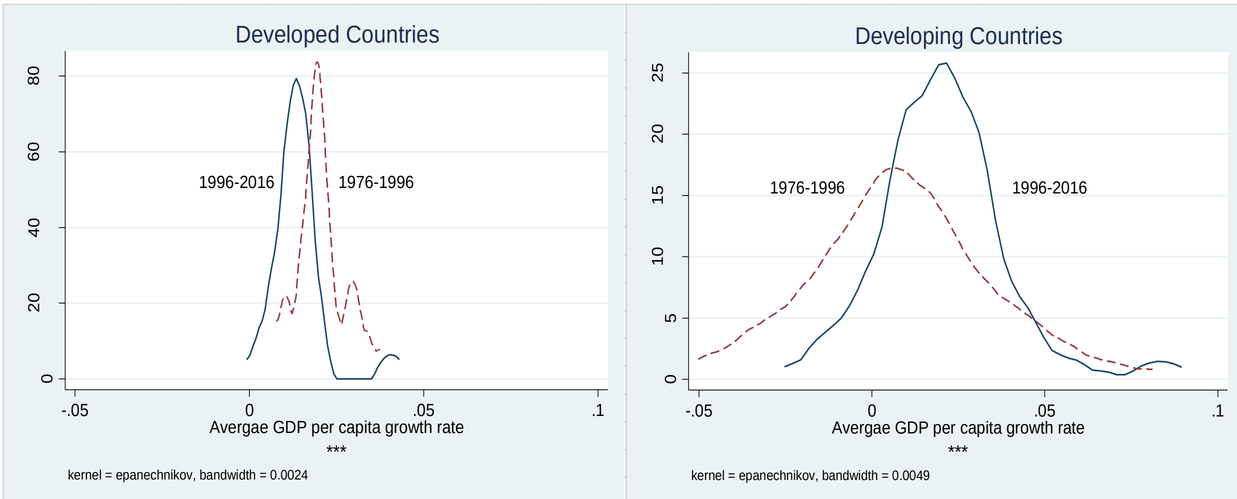
Source: authors' calculation with data from WDI (2019)

Figure 1 provides further evidence supporting Hypothesis #1 and Hypothesis #2. In fact, the distribution of 20-year GDP per capita growth rates shifted decisively to the right from 1976-1996 to 1996-2016for the group of developing countries (Panel A), while it shifted to the left for the developed group (Panel B).

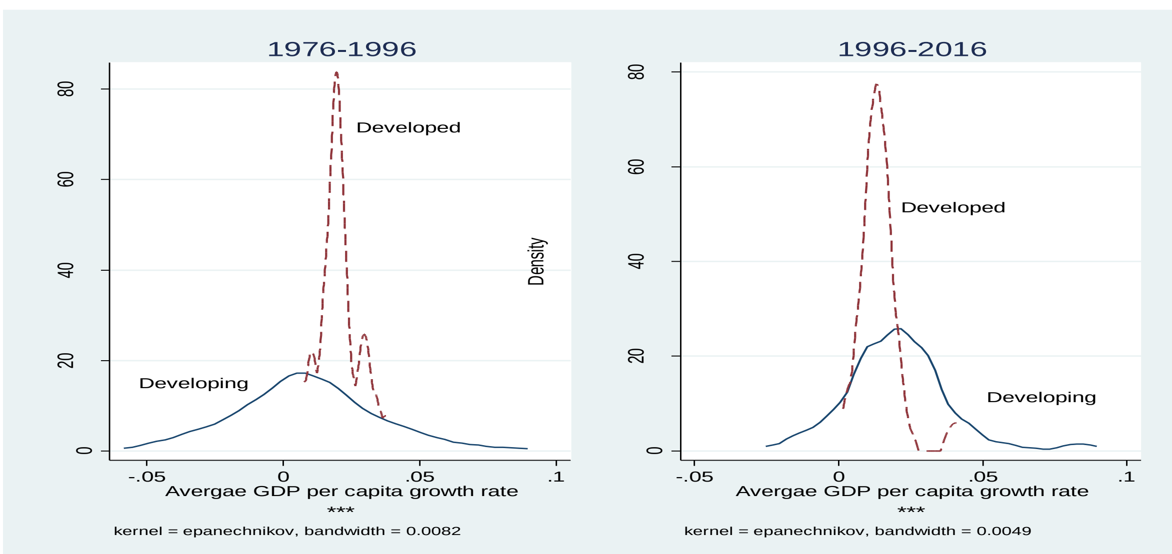
Figure 1 also provides evidence supporting Hypothesis #3. As shown in Panel B, the developing group was ahead of the developed group on the distribution of growth rates for the internet period (1996-2016), while the developing group was behind in the previous period (1976-1996).

Figure 1: Distribution of 20-year GDPC growth rate

Panel A: The shift from 1976-1996 to 1996-2016: developing vs. developed countries



Panel B: Developing vs. developed countries in 1976-1996 and 1996-2016



4. Empirical specification and estimation techniques

4.1. Empirical specification

The empirical specification employs a dynamic panel data approach,[11]which takes the following form:

$$Growth_{it} = \beta_0 + \beta_1 Growth_{it-1} + \beta_2 Income_{it-1} + \beta_3 Internet_{it-1} + \beta_4 Internet_{it-1} * Backward_i + X_{it}^{'} B + \mu_i + \vartheta_t + \varepsilon_{it} \quad (8)$$

where subscripts i and t indicate country i in year t, respectively; $\mu_i$represents country-specific characteristics;$\vartheta_t$represents time-fixed effects; and$\varepsilon_{i,t}$ is the random error term. The variables are defined below.

$Growth_{it}$ is annual real GDP per capita growth and its lag,$Growth_{it-1}$,is included to capture the unobserved factors that underlie the persistent pattern of the dependent variable.$Income_{it-1}$isthe initial level of per capita income, which is measured as the logarithm of GDP per capita measured in constant purchasing power parity (PPP) dollars; This variable is important for controlling the convergence effect specified by Barro (1991, 1997) and Barro and Sa-la-i-Martin (1995).

$Internet_{it-1}$is the logarithm value of the level of internet penetration at the beginning of each period, which is measured as the number of internet users per 100 population.[12]Note that the internet penetration is more meaningful than the broadband penetration for two main reasons. First, the former better captures the efforts of a nation in embracing the ICT revolution for learning, while the latter is, to certain extent, biased toward the infrastructure condition. Second, the data coverage of internet penetration is far more complete than that of broadband penetration in both the number of countries and the time span.

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[11] Islam (1995); Temple (1999); among many growth studies using this approach are Acemoglu et al. (2001, 2009), Forbes (2000), Eicher and Schreiber (2010), and d'Agostino et al. (2016).

[12] Using the log value of the internet penetration is better in enhancing its normal distribution and capturing its non-linear effect.

$Backward_i$is a dummy variable, which is equal to 1 if the country belongs to the group of countries defined as "backward" and 0 otherwise (see Appendix1 for details). Note that the dummy variable *backward* does not stand alone in Eq (8), because the inclusion of country-fixed effect μ_i causes its drop. The paper uses alternative classifications of countries as backward to examine whether these groups of countries can reap great growth gains from internet adoption. The interaction term $Internet_{it-1} * Backward_i$is used to capture this enhanced effect. The effect of internet adoption on growth in the average developing economy, therefore, is (β_3 + β_4), of which $\beta_3$is the effect for the average developed country and $\beta_4$is the enhanced effect. The inclusion of the interaction term$Internet_{it-1} * Backward_i$allows the model to achieve two apparently conflicting objectives at the same time. On the one hand, it makes it possible to control for fixed effects to reduce the omitted variable bias caused by the correlation between the explanatory variables and the country-fixed effect. On the other hand, it retains the valuable information associated with country heterogeneity (Temple, 1999), which may be the key source of persistent economic performance disparities among countries (Durlauf and Quah, 1998; Durlauf, Johnson and Temple, 2005).

$X_{it}^{'}$ is a vector of the control variables that has potential links with growth, which include $Institution$, $Investment$, $Government$, $Inflation$, and $Year$. The variable$Institution$ represents the institutional quality, for which we use as a proxy the rule of law index derived from the World Governance Indicators (WGI) dataset.[13]Previous studies have found significant evidence of the positive effect of institution quality on growth (for example, Barro, 1991; Rodrik, Subramanian, and Trebbi, 2004; Hart, 1997; Eicher et al. 2006; Vu, 2011), suggesting that the coefficient of $Institution$should take a positive sign.

$Investment$ captures the intensity of capital investment in the economy, which is defined asthe gross capital formation as a percentage of GDP. This variable is expected to take a

[13] This index is defined as the "perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence." (Kaufmann, Kraay, and Mastruzzi 2006). The annual data from the WGI dataset are available from 1996 onwards, with the exception of 1998 and 2000. The data for each of these two years are assumed to be the mid-point of the values observed for its previous and following years.

positive sign, as evidenced by previous studies such as Barro (1997) and Mankiw, Romer, and Weil(1992).

$Government$ captures the tax burden on the economy, which is proxied by final government consumption as a percentage of GDP, while $Inflation$ is the annual inflation rate, which captures macroeconomic instability. It is expected that the coefficients of $Government$ and $Inflation$ will be negative (King and Rebelo, 1990; Hansson and Henrekson, 1994; Barro, 1997; Acemoglu et al., 2003).

The variable $Year$ can be used to provide a quick assessment of the effect of time trends on economic growth. While the time-fixed effects control for the effect specific to each year such as economic/financial crisis, disruptive technological progress, and conflict eruptions, the time trend variable captures the possible time effect that is constant for each year. It is likely that the rapid progress of technology and globalization along with the rise of two giant markets – China and India, would give the time trends some positive effect. It should be noted that the time trend is included only in the regressions that do not control for time-fixed effects.

Table 2 provides summary statistics of the key variables in Eq (8). The empirical estimations are conducted for the panel dataset of 163 countries over the period from 1996 to 2016.

Table 2: Summary statistics (1996-2016; 163 countries)

Variables	Definition	Number of observations	Unit	Mean	Std. Dev.
Growth	GDP per capita growth	3,716	%	2.4	6.1
Institution	Rule of Law index	3,725		0.0	1.0
Income	Log of GDP per capital (2010 PPP$)	3,729		9.1	1.2
Internet	Log of number of internet users per 100 population	3,604		2.0	2.2
Investment	Gross fixed capital formation as a share of GDP	3,245	%	22.7	9.6
Govt. spending	General government final consumption expenditure as a share of GDP	3,261	%	16.0	6.2
Inflation	Annual inflation rate	3,388	%	7.3	26.6

Notes: The data for all variables, with the exception of Institution, are derived from the World Bank's World Development Database. The Rule of Law index is from the World Governance Indicators dataset.

4.2. Estimation techniques

Omitted variable bias (OVB) and simultaneity are the major econometric concerns we attempt to address. To reduce the magnitude of OVB, country-specific effects and time dummies should be included as a natural way to control for the effects of missing or unobserved variables, which are potentially correlated with explanatory variables (Hsiao, 2003). As argued by Kiviet (1995), including country and time dummies, known as the Least Square Dummies Variable (LSDV), is an effective way to handle dynamic panel bias. Taking into account these insights, country-fixed effects and time factors are included in all regressions to minimize the potential problem of OVB. Note that the time trend and time dummies are two alternatives to control for time influence. While the inclusion of time trend detects a consistent influence of the time factor overtime; that of year dummies controls for the time influence specific to each year.

However, controlling for country- and time-fixed effects does not help address the potential endogeneity of other regressors (Roodman, 2009b). One effective way to overcome this problem is the employment of the generalized method of moments (GMM) approach, which is proposed by Holtz-Eakin, Newey, and Rosen (1988) and further developed by Arellano and

Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998). Since their introduction, GMM techniques have become increasingly popular in the empirical economic growth literature for examining causal relationships from panel data.[14]

According to Arellano and Bover (1995), Blundell and Bond (1998), and Bond, Hoeffler, and Temple (2001), the GMM estimators offers several important advantages compared to other estimation techniques. First, they are designed for analyzing panel data in which the correlation between the lagged dependent variables and the error term may be significant. Second, GMM estimators take into account the presence of country-fixed effects. Third, they address the heteroscedasticity and serial correlation potentially faced by the error term. Finally, they allow some regressors to be endogenous, using their own lags as "internal" instruments.

When employing the GMM procedure, one can choose between two estimators: First Differenced-GMM (FD-GMM) and System-GMM (SYS-GMM). The SYS-GMM estimator, developed by Arellano and Bover (1995) and Blundell and Bond (1998), is considered an important improvement over the FD-GMM estimator, which was proposed by Holtz-Eakin, Newey, and Rosen (1988), and developed by Arellano and Bond (1991). As demonstrated by Soto (2009), the SYS-GMM estimator is superior to the other estimators, including the FD-GMM estimator, because of its reduced bias and higher efficiency. Furthermore, the SYS-GMM works better than the FD-GMM when the number of entities (such as countries) is small and the dependent variable is closer to a random walk (Blundell and Bond, 1998). More specifically, Bond, Hoeffler, and Temple (2001) demonstrate that SYS-GMM is better suited than FD-GMM for empirical studies of growth. The consistency of the SYS-GMM estimator, however, depends heavily on the assumption that its lagged change instruments are uncorrelated with the error terms (Roodman, 2009b).[15]This assumption, however, is unlikely to hold when the lagged change, such as that for internet penetration, is influenced by country-fixed effects (Vu, 2019).

[14]For example, see Caselli, Esquivel and Lefort (1996), Benhabib and Spiegel (1994, 2000), Easterly, Loayza and Montiel (1997), Forbes (2000), Beck, Levine and Loayza (2000), Levine, Loayza, and Beck (2000), Forbes (2000), Acemoglu, Johnson, Robinson, and Yared (2008), Giuliano and Ruiz-Arranz (2009), and Eicher and Schreiber (2010).

[15]It is critical to the validity of the moment conditions $E\left[\Delta y_{i,t-1}\varepsilon_{i,t-1}\right]=0$, where y is the dependent variable and $t\geq 3$.

To overcome this vulnerability, country fixed effects are included in all the SYS-GMM estimations.

For a GMM estimation to yield consistent estimates, it has to pass two tests: The Arellano-Bond AR(2) test and the Hansen test. While the null hypothesis for the Arellano-Bond AR(2) test is of the nonexistence of second order autocorrelation in the residuals, that for the Hansen test is of the validity of instruments as a group. A GMM estimation is valid only if the p-values obtained from these two tests are higher than the 10% threshold.

5. Estimation results

The estimation results are reported in Tables 3, 4, and 5. Each table contains results from three estimators: FE, OLS-FE, and SYS-GMM. Note that the p-values from the AR(2) and Hansen tests reported in each table confirm the validity of its GMM estimation. As presented in Section 4, the SYS-GMM results can be considered the most reliable for interpreting the findings.

5.1. The Internet-growth link

The estimations in Table 3 are focused on evaluating the overall effect of the internet on worldwide growth. For this purpose, the interaction term *L1.Internet*Backward* is excluded from the regression model. Two main findings stand out from Table 3. First, the coefficients of the key variables, including *L1.Income*, *Institution, Investment, Govt. spending,* and *Inflation*, which are widely used in the growth literature, take their expected signs and are statistically significant. This finding lends support to the soundness of the basic model. Second, the coefficient of the variable *L1.Internet* is positive and robustly significant at the 1% significance level in all regressions. Its estimated magnitude of 0.5, reported in Column (4), indicates that, for an average country, a 10% increase in internet adoption will raise the growth rate by 0.05% points.[16]

[16]Czernich et al. (2011) find that raising broadband penetration by 10% points would boost GDP per capita growth by 0.9 to 1.5% points. Although this study and our paper examine the effect of two different measures of ICT penetration, their results lend support to one another.

Table 3: Internet penetration and GDP per capita growth

Dependent variable: Annual GDP per capita growth (%)

Variable	**OLS-FE**		**SYS-GMM**
	(1)	**(2)**	**(3)**
L1.Growth	0.147***	0.143**	0.021
	(0.06)	(0.06)	(0.04)
L1.Income	-0.086***	-0.080***	-0.226***
	(0.01)	(0.01)	(0.04)
L1.Internet	0.515***	0.413***	0.860***
	(0.08)	(0.10)	(0.19)
Institution	1.526***	1.591***	2.12
	(0.53)	(0.53)	(2.06)
Investment	0.062*	0.066*	0.032
	(0.04)	(0.04)	(0.042)
Govt. spending	-0.214***	-0.153***	-0.824***
	(0.05)	(0.05)	(0.27)
Inflation	-0.014***	-0.014***	-0.014*
	(0.01)	(0.01)	(0.007)
Time trend (Year)	0.019		0.242***
	(0.03)		(0.08)
Country-FE	Yes	Yes	Yes
Time-FE	No	Yes	No
N	3,006	3,006	3,006
R-squared	0.32	0.38	
GMM tests (p-value)			
AB test of AR(2)			0.118
Hansen test of overid. restrictions			0.350 (#lag=119)

*Notes: The figures in parentheses are robust standard errors. For the GMM estimations, the GMM Instruments are the first and second lagged values of the explanatory variables and the IV Instruments include time dummies, country dummies, and income group dummies; The count of instruments (lags) used for each Hansen test is reported under its p-value. Significance levels: ***p<.01; **p<.05; *p<.10. The time dummies are used only as IV instruments.*

5.2. The backward advantage and the internet-growth link

Having evidenced the significant effect of internet use on per capita income growth, we are now focused on the main research question: "do 'backward' countries reap greater growth gains from internet adoption?" We use the 1990 per capita income (measured in PPP$) to define the term backwardness according for which the sample of 163 countries examined in this paper are divided into four income quarters. The dummy *Backward* represents the countries belonging to the three lower income quarters. Under this definition, the "backward" group comprises 123 countries with an income level below the 75-percentile, while the remaining 40 countries in the top income quarter constitute the base group(see Appendix 1 for details). It should be noted that using the 1990 income level makes this classification straightforward and exogenous to the effect of internet penetration

Table 4 reports results from regressions based on Eq (8). The coefficient on the interaction term *Backward*L1.Internet,* which captures the enhanced effect of the internet on growth in "backward" economies, provides a measures of the backwardness advantage. A number of valuable findings stand out from Table 4.

First, the coefficients of the key covariates take their expected signs and are statistically significant in most regressions. In particular, the coefficient of *L1.Income* is negative and significant at the 1% level in all regressions, which supports the conditional convergence effect, which has been found extensively in previous studies. The coefficient on *Institution* is positive in all regressions and significant at the 1% level in regressions (1) and (2), which implies a significant link between institutional quality and growth. A possible reason for this coefficient being less significant in the GMM estimation is its more effective control for endogeneity. Similarly, the coefficient on *Investment* is positive in all regressions but statistically significant only in regressions (1) and (2). On the other hand, the coefficients on *Govt_spending* and *Inflation* are negative and statistically significant in all regressions, which means these two variables have a significant adverse effect on growth.

Second, the coefficient on *Year* (time trend) is positive and significant at the 1% significance level in regression (3). Note that, the estimate is dropped in regression (2) because this estimation includes time dummies. This finding supports the hypothesis that, on average, growth tends to accelerate overtime over the 1996-2016 period. That is, technology progress, globalization, and new waves of reforms across countries appeared to have a long-term effect on global growth.

Lastly but most importantly, the coefficients on *L1.Internet*and its interaction term provide valuable insights on the effect of internet on growth. The coefficient on *L1.Internet* is positive in all regression but statistically significant only in regression (1). This coefficient, however, is not significant in regression (2), which controls for time-fixed effects, and in regression (3), which is most effective in controlling for endogeneity. Note that the coefficient on *L1.Internet* captures the effect of internet penetration on growth in the base group, which consists of high-income countries. This finding suggests that the effect of internet penetration has a positive effect on growth in high income nations but the evidence is not robust enough to be statistically significant.[17]On the other hand, the coefficient on the interaction term, *L1.Internet*Backward*, is statistically significant in all regressions. This result means that the effect of internet adoption on growth in developing countries is significantly larger than in high-income nations.

[17]Several explanations are possible. First, Internet is measured in this paper is based on the number of internet users per 100 inhabitants (not broadband users due to the huge amount of zeros in early years in developing countries). For developed countries there is certainly some kind of saturation effect as the number of Internet users does not grow much after 2005 and the broadband penetration may be a more meaningful measure to capture its effect on growth. Second, population aging in developed countries is an apparent problem. As its population gets aging, a country's internet penetration rate increases but its economic performance would suffer.

Table 4: Backwardness advantage and the enhanced growth effect of internet

Dependent variable: Annual GDP per capita growth (%)

	OLS-FE		**SYS-GMM**
	(1)	**(2)**	**(3)**
L1.Growth	0.147***	0.143**	0.028
	(0.056)	(0.058)	(0.04)
L1.Income	-0.088***	-0.081***	-0.236***
	(0.01)	(0.01)	(0.038)
L1.Internet	0.330**	0.106	0.015
	(0.131)	(0.161)	(0.324)
L1.Internet*Backward	0.184*	0.257**	0.896**
	(0.111)	(0.114)	(0.366)
Institution	1.594***	1.717***	1.196
	(0.534)	(0.534)	(2.04)
Investment	0.060*	0.065*	0.01
	(0.037)	(0.037)	(0.039)
Govt. spending	-0.218***	-0.157***	-0.703***
	(0.053)	(0.052)	(0.244)
Inflation	-0.014***	-0.014***	-0.013*
	(0.005)	(0.005)	(0.007)
Time trend (Year)	0.035		0.324***
	(0.027)		(0.087)
Country-FE	Yes	Yes	Yes
Time-FE	No	Yes	No
N	3,006	3,006	3,006
R-squared	0.32	0.38	
P-value of tests			
AB test of AR(2)			0.173
Hansen test of overid. restrictions			0.399 (#lag=118)
Joint significant of Internet and its interaction term	0.000	0.000	0.000

*Notes: The figures in parentheses are robust standard errors. For the GMM estimations the GMM Instruments are the first and second lagged values of the explanatory variables and the IV Instruments include time dummies, country dummies, and income group dummies; The count of instruments (lags) used for each Hansen test is reported under its p-value. Significance levels: ***p<.01; **p<.05; *p<.10.*

5.3. The backward advantage and the internet-growth link: a deeper look

In the previous subsection, we examined the entire "backwardness" group, which consists of the three lower income quarters: the lowest (which includes the countries with per capita income below the 25-percentile); the lower-middle (from 25-percentile and below the 50-percentile); and the upper-middle (from 50-percentile and below 75-percentile). We create dummy variables for these three quarters to capture their individual effect: *Backward1* for the lowest income quarter; *Backward2* for the lower-middle; and *Backward3* for the higher-middle

In this subsection we look deeper into which lower income quarters tend to reap great growth gains from internet adoption. For this purpose we replace the interaction term *L1.Internet*Backward* with three new interaction terms, *L1.Internet*Backward1*, *L1.Internet*Backward2,* and *L1.Internet*Backward3.*Table 5 reports the results from regressions based on this modified model.

Similar to what we have found from Table 4 above, the coefficients on the covariates take their expected signs and are significant in regressions (1) and (2) while they are less significant in regression (3), in which simultaneity is eliminated. At the same time, the coefficient on the time trend is positive and significant at the 1% significance level, which confirms the positive effect of time on growth, which is associated with technology progress, enhanced global integration, and new waves of economic reforms across nations. Furthermore, the coefficient on *L1.Internet* is positive but not significant, while the combined effect of the coefficients on the three interaction terms is statistically significant at the 10% level in regression (1) and at the 5% significance level in regressions (2) and (3).

The most important finding from Table 5, however, is that not all the coefficients on the three interaction terms are significant although they are all positive. In fact, only the coefficient on *L1.Internet*Backward3* is significant in all ~~the~~ three regressions. This finding suggests that being backward only is not enough to benefit from the backwardness advantage in the information age. Reaching a certain level of income, which means a certain level of development, appears to play an important role in reaping the internet-enabled growth gains.

Table 5: Backwardness advantage and the enhanced growth effect of internet – a deeper look

Dependent variable: Annual GDP per capita growth (%)

Variable	OLS-FE		SYS-GMM
	(1)	(2)	(3)
L1.Growth	0.148***	0.143**	0.01
	(0.056)	(0.058)	(0.042)
L1.Income	-0.088***	-0.081***	-0.256***
	(0.01)	(0.01)	(0.034)
L1.Internet	0.334**	0.106	0.106
	(0.132)	(0.168)	(0.369)
L1.Internet* Backward1	0.198	0.276*	0.615
	(0.141)	(0.146)	(0.462)
L1.Internet* Backward2	0.145	0.232*	0.701
	(0.115)	(0.124)	(0.499)
L1.Internet* Backward3	0.214*	0.268**	1.659**
	(0.126)	(0.123)	(0.763)
Institution	1.566***	1.700***	3.373
	(0.534)	(0.535)	(2.128)
Investment	0.06	0.065*	-0.023
	(0.037)	(0.037)	(0.031)
Govt. spending	-0.218***	-0.157***	-0.652***
	(0.053)	(0.052)	(0.23)
Inflation	-0.013***	-0.013***	-0.01*
	(0.005)	(0.005)	(0.005)
Time trend (Year)	0.034		0.323***
	(0.027)		(0.084)
Country-FE	Yes	Yes	Yes
Time-FE	No	Yes	No
N	3,006	3,006	3,006
R-squared	0.32	0.38	
P-value of tests			
AB test of AR(2)			0.178
Hansen test of overid. restrictions			0.707 (#lag=121)
Combined effect[a]	0.097	0.026	0.033

*Notes: The figures in parentheses are robust standard errors. For the GMM estimations the GMM Instruments are the first and second lagged values of the explanatory variables and the IV Instruments include time dummies, country dummies, and income group dummies; The count of instruments (lags) used for each Hansen test is reported under its p-value. [a]Using Stata command "lincom" for the three interaction terms to test the significance of their combined effects. Significance levels: ***p<.01; **p<.05; *p<.10. The time dummies are used only as IV instruments.*

5.4 Some theoretical implications

This section is devoted to further discussing the results with specific emphasis on whether the established results confirm the findings of Papaioannou and Dimelis (2007) and Dedrick et al. (2013) and Niebel (2018) that no statistical evidence is apparent to confirm the scholarly position that emerging and developing countries are benefiting more from ICT compared to developed countries[18]. As apparent in the previous sections pertaining to the presentation of results, the findings of Papaioannou and Dimelis (2007) and Dedrick et al. (2013) and Niebel (2018) cannot be confirmed in the present study. In what follows, we clarify why the results in this study do not support the results of the previous research, notably, in terms of: sample, methodology and theoretical underpinnings underlying catch-up modeling. These distinctive features are expanded in the same chronology as highlighted.

First, there are differences with respect to the countries in the sample. While Niebel (2018) has focused on a panel of 59 countries for the period 1995–2010 and the earlier studies by Papaioannou and Dimelis (2007) and Dedrick et al. (2013) covered even less countries, this study is concerned with a panel of 163 countries from 1996 to 2016. From intuition, sampling improvements in terms of space (difference of 104 countries) and time (i.e. 2011 to 2016) can partly elicit why the previous findings do not withstand empirical scrutiny. In essence, the 104 more countries, now covering also some of the least developed countries, can substantially weigh on the underlying findings and ICT penetration might have significantly increased between 2011 and 2016 in developing countries to elucidate cross-country differences in economic development between developed countries and their developing counterparts.

Second, the ICT measure differs. Previous studies by Papaioannou and Dimelis (2007) and Dedrick et al. (2013) and Niebel (2018) use monetary measures of general ICT capital (Hardware, Software and Telecommunication Equipment), whereas this study focus on the number of internet users per 100 populations. Internet penetration is a much broader measure

[18] More specially, Papaioannou and Dimelis (2007: 1992) assert "whereas evidence is provided that developing countries have started to benefit from ICT, although its impact is lower, compared to that of developed countries"; while Dedrick et al. (2013:111) confirms "there is no significant difference between developed and developing countries regarding the effect of IT capital stock on output"

which also measures access to knowledge by the whole population and not just ICT capital by firms. So our measure also captures knowledge spillovers. This view is supported by the previous findings of Dedrick et al. (2013) which show that the productivity effects of general ICT capital are moderated by the level of Internet penetration in the respective country.

Third, disparities in methodologies are also apparent given that the studies of Papaioannou and Dimelis (2007) and Dedrick et al. (2013) and Niebel (2018) are largely based static models whereas dynamic estimated techniques are taken on board in this study. This difference in estimation approach motivates the third distinctive feature which pertains to theoretical underpinnings surrounding the modeling of the catch-up process.

Fourth, compared to static models, dynamic models are tailored to be more relevant in estimating catch-up because a lagged dependent variable is included as an independent variable of interest, such that the information criterion used to assess the rate of catch-up and corresponding time to full catch-up is contingent on the estimated lagged dependent variable (Asongu and Nwachukwu, 2016). Moreover, as clarified in previous sections of this study, modeling catch-up with the GMM estimation technique is consistent with theoretical underpinnings underlying the Solow-Swan model, such that, cross-country differences in the outcome variables (and hence catch-up) is apparent when there are cross-country differences in determinants of the outcome variable which are captured in the conditioning information set. While ICT penetration and especially Internet penetration has reached saturation levels in developed countries, the fact that developing countries still have a high potential for the attendant ICT penetration (Minkoua Nzie, Bidogeza & Ngum, 2018; Ejemeyovwi, J. O., and Osabuohien, 2020; Kuada and Mensah, 2020; Tchamyou, 2019), implies that catch-up in economic development can be apparent, granting that, information technology is exogenous to economic development. Accordingly, there is a growing strand of literature on the importance of ICT in socio-economic development in developing countries (Gosavi, 2018; Isszhaku, Abu & Nkegbe, 2018; Humbani and Wiese, 2018; Karakara and Osabuohien, 2019).

6. Concluding implications, caveats and future research directions

"Knowledge is the engine of growth." To economists and policy makers alike, this statement made by Alfred Marshall more than 100 years ago is not only correct but also fundamental and strategic. Probably in this spirit, Gerschenkron (1962) postulated that developing countries have an advantage over developed nations because they can quickly and less riskily adopt knowledge in the forms of technology, methods of production, and management techniques that have been developed by the leaders. Since then, a number of studies have provided both theoretical models and empirical evidence supporting this backwardness advantage hypothesis. At the micro level, Foster and Rosenzweig (2010) provide robust empirical evidence and theoretical models to evidence that knowledge acquisition has significant effects on productivity improvement and investment in human capital, which all stimulate growth. However, empirical studies on the effect of the backwardness advantage on economic growth at national level remain scarce.

This paper set out to assess whether the findings of Niebel (2018) and the earlier studies by Papaioannou and Dimelis (2007) and Dedrick et al. (2013) withstand empirical scrutiny when more countries and contemporary data are taken on board. The findings in as sense run counter to Papaioannou and Dimelis (2007) and Dedrick et al. (2013) and in particular Niebel (2018) who concludes that emerging and developing countries are not gaining more from investment in ICT than their developed counterparts. The relevance of extending the work by Papaioannou and Dimelis (2007), Dedrick et al. (2013) and Niebel (2018) to scholars and policy makers has been clarified in the introduction while the "further discussion of results" section in the light of difference in sample, methodology and theoretical underpinnings surrounding catch-up modeling.

The digital revolution's impact on economic growth has been found significant across countries and sectors. However, the importance of the channels through which this impact is transmitted may vary by country depending on their level of development. On the one hand, it is expected that developed countries are in a better position to benefit from embracing the digital transformation, especially in the adoption of the technologies such as artificial intelligence (AI), robotics, and Internet of things (IoT)that require more advanced infrastructure and human capital. On the other hand, developing countries appear to reap greater gains from the internet and its related technologies such as social media and platform/sharing economy thanks to the backwardness advantage, especially in learning, innovation, marketing, and job search. The findings from this paper confirm these assessments.

The additional effect of digital technologies on economic growth in lower-income countries via the channel of learning and technology acquisition suggests that this channel should be a primary focus of digital transformation strategies, especially in capital investment plans and regulatory reform efforts in developing countries. More specifically, governments in developing countries should effectively take on the following top policy priorities. The first priority is to promote investments in digital infrastructure and strengthening cyber security, especially broadband, fiber, and cloud computing. For lower-income countries, this investment is most likely more urgent and efficient than investing in 5G mobile technology because without a good fiber backbone, there are not many benefits from 5G.[19] Second, the government should strongly encourage firms and people to engage in technology acquisition, knowledge diffusion, and learning. Third, the less developed sectors such as agriculture, tourism, as well as small and medium enterprises (SMEs), which can gain most from their backwardness advantage, should receive special support from the government in their digital learning and transformation endeavors.

After discussing the practical contributions of the study, it is worthwhile to clarify that this study is positioned on assessing theoretical underpinnings surrounding the thesis that catch-up in economic development is contingent on cross-country differences in technology and other determinants of economic development. Accordingly, research can either be positioned on confirming an existing theoretical exposition or providing theory-building insights. The modest contribution of this research to scholarship is in the former framework. Hence, no theoretical contributions are consistent with the motivation and purpose of the study.

[19] The 5G mobile technology is expected be superior to its predecessors: (i) enhanced mobile broadband experience with peak speeds of up to 20Gbps (20-fold increase over 4G); (ii) ability to support large-scale M2M communication; and (iii) ultra-reliability and low latency that support drones and driverless cars. It is obvious that a less developing country would benefit less from 5G if it is still behind too far in embracing 4G, especially for learning and technology acquisition.

On the caveats of the study, it is important to note that while the internet is established to contribute to the economic growth catch-up process, internet is not solely responsible for the catch-up because the modeling exercise is within the framework of conditional beta convergence. Accordingly, while all adopted variables in the conditioning information set contribute towards the catch-up, internet is one of the most significant factors. Moreover, in the real world, the internet and growth do not interact in isolation but require other macroeconomic factors, which justified the need for a conditional convergence modeling approach. Other limitations of the study pertain to *inter alia*, the fact that: (i) causality cannot be exhaustively established with the adopted empirical strategies and (ii) owing to constraints in data availability at the time of the study, more updated measures of information technology could not be taken on board.

In the light of the above caveats, future research can enhance the established findings by assessing how the findings are relevant within country-specific frameworks in order to engender more country-specific implications. Moreover, as more data become available, smartphones which entail the mobile phone, the internet connection and other apparent information technology externalities, could be used as a more appropriate and holistic measure of information technology.

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Appendix **1: The list of countries and backwardness advantage by definition**

(Countries are sorted by 1990 income within their group)

Economy	**Per capita income in 1990 (PPP$)**	**Backwardness advantage by definition**	
		Developing by UN (1990) classification	**The level of 1990 income below the 75th percentile**
Developed countries			
1. Luxembourg	57,618	No	No
2. Switzerland	48,182	No	No
3. Norway	42,814	No	No
4. United States	37,062	No	No
5. Denmark	33,786	No	No
6. Netherlands	32,090	No	No
7. Austria	31,342	No	No
8. Canada	31,300	No	No
9. Germany	31,287	No	No
10. Italy	31,142	No	No
11. Sweden	30,934	No	No
12. Belgium	30,648	No	No
13. Japan	30,582	No	No
14. France	29,515	No	No
15. Finland	28,906	No	No
16. Australia	28,658	No	No
17. United Kingdom	26,828	No	No
18. Spain	23,759	No	No
19. New Zealand	23,671	No	No
20. Ireland	21,453	No	No
21. Greece	20,686	No	No
22. Israel	20,520	No	No
23. Portugal	20,167	No	No
Developing countries			
24. United Arab Emirates	110,433	Yes	No
25. Brunei Darussalam	84,672	Yes	No
26. Saudi Arabia	42,457	Yes	No
27. Bermuda	40,553	Yes	No
28. Macao SAR, China	40,365	Yes	No
29. Bahrain	35,113	Yes	No
30. Oman	35,042	Yes	No

31. Singapore	34,345	Yes	No
32. Bahamas, The	30,992	Yes	No
33. Hong Kong SAR, China	26,974	Yes	No
34. Cyprus	23,301	Yes	No
35. Puerto Rico	22,227	Yes	No
36. Russian Federation	20,639	Yes	No
37. Czech Republic	20,023	Yes	No
38. Gabon	19,501	Yes	No
39. Antigua and Barbuda	16,381	Yes	No
40. Malta	16,176	Yes	No
41. Venezuela, RB	14,451	Yes	Yes
42. Barbados	14,434	Yes	Yes
43. St. Kitts and Nevis	14,326	Yes	Yes
44. Seychelles	14,217	Yes	Yes
45. Mexico	13,070	Yes	Yes
46. Kazakhstan	13,050	Yes	Yes
47. Trinidad and Tobago	12,255	Yes	Yes
48. Korea, Rep.	11,633	Yes	Yes
49. Iraq	11,522	Yes	Yes
50. Romania	11,422	Yes	Yes
51. Turkey	11,400	Yes	Yes
52. Iran, Islamic Rep.	11,393	Yes	Yes
53. Argentina	10,816	Yes	Yes
54. Malaysia	10,552	Yes	Yes
55. Suriname	10,545	Yes	Yes
56. Ukraine	10,464	Yes	Yes
57. Brazil	10,345	Yes	Yes
58. Poland	10,277	Yes	Yes
59. Algeria	10,237	Yes	Yes
60. Uruguay	9,841	Yes	Yes
61. St. Lucia	9,831	Yes	Yes
62. South Africa	9,696	Yes	Yes
63. Macedonia, FYR	9,633	Yes	Yes
64. Bulgaria	9,297	Yes	Yes
65. Chile	8,992	Yes	Yes
66. Azerbaijan	8,513	Yes	Yes
67. Belarus	8,354	Yes	Yes
68. Turkmenistan	8,317	Yes	Yes
69. Botswana	8,110	Yes	Yes
70. Georgia	8,007	Yes	Yes
71. Lebanon	7,858	Yes	Yes

72. Panama	7,855	Yes	Yes
73. Costa Rica	7,787	Yes	Yes
74. Colombia	7,534	Yes	Yes
75. Ecuador	7,472	Yes	Yes
76. Mauritius	7,387	Yes	Yes
77. Jamaica	7,286	Yes	Yes
78. Grenada	7,242	Yes	Yes
79. Dominica	6,730	Yes	Yes
80. Thailand	6,650	Yes	Yes
81. Jordan	6,283	Yes	Yes
82. Paraguay	6,036	Yes	Yes
83. Egypt, Arab Rep.	5,909	Yes	Yes
84. Fiji	5,891	Yes	Yes
85. Namibia	5,719	Yes	Yes
86. Tunisia	5,615	Yes	Yes
87. St. Vincent & Grenadines	5,576	Yes	Yes
88. Dominican Republic	5,477	Yes	Yes
89. Eswatini	5,378	Yes	Yes
90. Peru	5,313	Yes	Yes
91. Belize	5,166	Yes	Yes
92. Congo, Rep.	5,140	Yes	Yes
93. Mongolia	5,123	Yes	Yes
94. Guatemala	5,101	Yes	Yes
95. Albania	4,723	Yes	Yes
96. Indonesia	4,625	Yes	Yes
97. El Salvador	4,545	Yes	Yes
98. Philippines	4,010	Yes	Yes
99. Morocco	3,912	Yes	Yes
100. Armenia	3,742	Yes	Yes
101. Bolivia	3,707	Yes	Yes
102. Samoa	3,649	Yes	Yes
103. Tajikistan	3,645	Yes	Yes
104. Sri Lanka	3,612	Yes	Yes
105. Tonga	3,574	Yes	Yes
106. Kyrgyz Republic	3,475	Yes	Yes
107. Angola	3,431	Yes	Yes
108. Yemen, Rep.	3,327	Yes	Yes
109. Cote d'Ivoire	3,194	Yes	Yes
110. Honduras	3,172	Yes	Yes
111. Uzbekistan	3,071	Yes	Yes
112. Pakistan	3,055	Yes	Yes

113. Nigeria	3,042	Yes	Yes
114. Cameroon	3,020	Yes	Yes
115. Nicaragua	3,004	Yes	Yes
116. Marshall Islands	2,908	Yes	Yes
117. Guyana	2,843	Yes	Yes
118. Mauritania	2,807	Yes	Yes
119. Micronesia, Fed. Sts.	2,721	Yes	Yes
120. Zimbabwe	2,606	Yes	Yes
121. Vanuatu	2,549	Yes	Yes
122. Kenya	2,380	Yes	Yes
123. Papua New Guinea	2,374	Yes	Yes
124. Tuvalu	2,354	Yes	Yes
125. Zambia	2,342	Yes	Yes
126. Bhutan	2,325	Yes	Yes
127. Kiribati	1,961	Yes	Yes
128. Ghana	1,920	Yes	Yes
129. Solomon Islands	1,883	Yes	Yes
130. Senegal	1,845	Yes	Yes
131. India	1,755	Yes	Yes
132. Sudan	1,743	Yes	Yes
133. Lao PDR	1,708	Yes	Yes
134. Cabo Verde	1,657	Yes	Yes
135. Madagascar	1,653	Yes	Yes
136. Comoros	1,600	Yes	Yes
137. Guinea-Bissau	1,574	Yes	Yes
138. China	1,526	Yes	Yes
139. Gambia, The	1,506	Yes	Yes
140. Tanzania	1,473	Yes	Yes
141. Benin	1,463	Yes	Yes
142. Vietnam	1,453	Yes	Yes
143. Guinea	1,412	Yes	Yes
144. Congo, Dem. Rep.	1,387	Yes	Yes
145. Lesotho	1,379	Yes	Yes
146. Togo	1,350	Yes	Yes
147. Bangladesh	1,288	Yes	Yes
148. Mali	1,272	Yes	Yes
149. Sierra Leone	1,251	Yes	Yes
150. Nepal	1,198	Yes	Yes
151. Chad	1,110	Yes	Yes
152. Burundi	1,087	Yes	Yes
153. Equatorial Guinea	1,000	Yes	Yes

154. Central African Republic	925	Yes	Yes
155. Niger	895	Yes	Yes
156. Liberia	875	Yes	Yes
157. Rwanda	873	Yes	Yes
158. Burkina Faso	844	Yes	Yes
159. Uganda	769	Yes	Yes
160. Malawi	744	Yes	Yes
161. Myanmar	743	Yes	Yes
162. Ethiopia	652	Yes	Yes
163. Mozambique	379	Yes	Yes