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ICT DIFFUSION AND LABOR PRODUCTIVITY IN G20 COUNTRIES: A CRITICAL REVIEW OF THE EVIDENCE

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ABSTRACT

Information and communication technology (ICT) has reshaped how output is produced, traded and measured, yet whether its diffusion translates into reliable labor productivity gains remains contested, especially for G20 economies that together generate the bulk of global output. This review asks whether ICT diffusion is associated with labor productivity in G20 countries, whether the association differs between advanced and emerging members, and through which channels it operates. A structured critical review was conducted across Scopus, Web of Science and Google Scholar, combining technology terms (ICT diffusion, Internet use, broadband, digitalization) with outcome terms (labor productivity, output per worker, productivity growth) and G20 qualifiers; inclusion required peer-reviewed empirical work with a transparent estimation strategy, retaining core theoretical sources for interpretive scaffolding. Within this evidence base, the review prioritizes studies that use Internet users as a percentage of the population as the principal proxy for ICT diffusion, while evidence based on broadband, mobile subscriptions, ICT capital, or composite digitalization indices is treated as contextual rather than directly comparable. The evidence indicates a generally positive association that is neither immediate nor uniform: effects are larger in advanced economies and ICT-intensive sectors, conditional on human capital, institutional quality and diffusion stage, and concentrated in a roughly decade-long window in advanced-economy data before attenuating. G20 studies overwhelmingly model economic growth rather than labor productivity, and few track the full diffusion cycle. Apparent contradictions in the literature largely dissolve once differences in proxy, outcome, sample and horizon are recognized, implying three priorities for future research: target labor productivity directly rather than aggregate growth, span both growth and maturity phases of diffusion, and adopt estimation strategies that accommodate cross-sectional dependence and heterogeneity across G20 members.

KEYWORDS: ICT Diffusion, Labor Productivity, Internet Users, G20 Countries, Literature Review.

1. INTRODUCTION

The diffusion of information and communication technology (ICT) has come to define the productive infrastructure of contemporary economies, intermediating how firms allocate labor, how supply chains coordinate across borders, and how new knowledge spreads from laboratories into routine work. For the Group of Twenty, which jointly accounts for roughly four-fifths of global gross domestic product, the question is no longer whether ICT matters but whether its diffusion has translated into the productivity gains its theoretical promise implied. The evidence accumulated over the past quarter-century is uneven enough to make that question genuinely open.

Three observations motivate this review. The empirical record on ICT and aggregate productivity is mixed in a way that resists easy summary: some economies appear to extract sustained gains while others, equipped with comparable infrastructure, register only modest or transient effects. Most of the literature on the G20 specifically models economic growth rather than labor productivity, conflating two outcomes that capture different aspects of how technology reaches working people. And the temporal coverage of available studies rarely spans the full diffusion cycle, leaving open whether early gains generalize as Internet use approaches saturation in advanced members and continues to expand in emerging ones.

The aim of this paper is to consolidate what is known, expose where the evidence is weakest, and suggest where future work should concentrate. The scope is deliberately bounded to studies that examine an empirical link between an ICT measure and a productivity or growth outcome, with priority given to peer-reviewed sources offering transparent estimation strategies. The review organizes this material by mechanism and country coverage rather than chronologically, so that conditional patterns become visible and apparent contradictions can be diagnosed as differences in measurement and design rather than substantive disagreement. The paper proceeds through a description of methodology, a critical synthesis of the literature, a combined analysis of results and discussion, and a conclusion that draws out the implications for a focused research agenda on G20 economies.

2. METHODOLOGY

This paper applies a structured critical review rather than a fully protocol-driven systematic review or meta-analysis. The aim is to synthesize mechanisms, results and gaps across a

heterogeneous evidence base, not to enumerate every published estimate. Three databases were searched, namely Scopus, Web of Science and Google Scholar, using a triangulated keyword strategy designed to capture the technology side, the outcome side and the geographic focus of the inquiry.

Technology-side terms included ICT diffusion, Internet use, Internet users, broadband, mobile penetration and digitalization. Outcome-side terms included labor productivity, output per worker, productivity growth and total factor productivity. These were combined with G20-related qualifiers covering both the bloc as a whole and its individual members. Searches focused on the post-dot-com phase of ICT investment, the diffusion of high-speed Internet, the rise of mobile broadband and the early evidence on platform economies. This review gives priority to evidence employing Internet users as a percentage of the population as the ICT diffusion proxy. This choice is methodologically appropriate for three reasons. First, the indicator provides consistent coverage across both advanced and emerging G20 economies throughout the period under review, whereas broadband, ICT capital, and some digital infrastructure series are less consistently available for long cross-country panels. Second, it captures actual technology use rather than infrastructure capacity alone, which aligns more closely with the productivity channels emphasized in general-purpose-technology and absorptive-capacity perspectives. Third, it is used in several closely related labor-productivity studies, including Najarzadeh *et al.* (2014), Hsieh and Goel (2019), and Harrathi and Alshogheathri (2025). Studies employing broadband subscriptions, mobile cellular subscriptions, ICT capital stock or composite digitalization indices are therefore treated as contextual evidence within the broader ICT-productivity literature rather than as direct comparators for the principal ICT measure. Within this framing, the central evidentiary gap is that G20-focused studies have examined ICT effects on economic growth more often than on labor productivity directly, even though the two outcomes reflect partially distinct mechanisms.

Inclusion criteria favored peer-reviewed empirical studies that reported an estimated relationship between an ICT measure and either labor productivity or aggregate growth, used a transparent quantitative method, and described their sample, period and identification strategy clearly. Theoretical contributions were retained when they supplied the conceptual scaffolding needed to interpret empirical findings, including endogenous

growth theory, the general-purpose-technology framework, the productivity-paradox debate, human-capital theory, absorptive-capacity arguments and diffusion-of-innovations theory. Opinion pieces, consultancy reports without methodological detail and studies whose data sources could not be verified were set aside.

Approximately thirty empirical studies, alongside the core theoretical works that frame the field, satisfied these criteria. The sample spans cross-country panels, single-country and firm-level analyzes, growth-accounting exercises, and recent applications of dynamic panel methods. Rather than presenting these studies sequentially, the synthesis groups them by mechanism, country coverage and method, which permits direct comparison of where findings converge, where they diverge, and what those divergences attribute to differences in measurement and design.

3. LITERATURE REVIEW

3.1. *Theoretical Foundations*

The case for studying ICT as a productivity input draws on several overlapping traditions. Endogenous growth theory locates technological change inside the economic system, treating innovation as a deliberate response to incentives rather than an external gift; Romer (1990) shows how investment in knowledge yields increasing returns at the aggregate level when ideas can be combined non-rivalrously across users. Lucas (1988) places human capital at the heart of long-run growth differences, an emphasis that proves consequential when assessing why otherwise similar economies extract very different productivity gains from comparable digital infrastructure. The neoclassical scaffolding provided by Solow (1956, 1957) supplies the residual within which much of the ICT-productivity discussion has been organized, with the Solow productivity paradox of the 1980s naming the puzzle that motivated three decades of subsequent empirical work.

A second strand frames ICT as a general-purpose technology whose effects unfold through complementary investments in skills, organizational practices and process redesign. Bresnahan and Trajtenberg (1995) and Bresnahan et al. (2002) develop this view formally and document its empirical correlates, showing that gains from computing accrue chiefly to firms that reorganize around the new technology rather than those that merely install it. Cohen and Levinthal (1990) provide the conceptual hinge of absorptive capacity, the idea that prior investment in related knowledge

determines whether an economy or firm can productively use what it acquires from outside; this argument later becomes central to explaining why G20 emerging members often realize smaller and slower gains than advanced peers. The strengths of these foundations are conceptual clarity and broad applicability across sectors and country settings. Their main weakness is empirical: absorptive capacity and complementary investments are notoriously hard to measure consistently, which leaves substantial space for proxy choices to shape results.

A third tradition treats ICT as an innovation whose adoption follows a recognizable temporal arc. Diffusion-of-innovations reasoning predicts an S-shaped trajectory in which initial uptake is slow, an inflection accelerates take-up among the middle of the distribution, and saturation eventually flattens further gains. David (1990) draws an extended historical parallel with electrification, arguing that broad productivity effects materialized only decades after the underlying technology became available because organizational and infrastructural reconfiguration takes time. Becker (1975) supplies the deeper microfoundation by treating skill formation as a deliberate investment whose returns depend on the technological environment in which it is deployed. The pairing of diffusion and human-capital theory yields a falsifiable prediction that the literature reviewed below repeatedly supports: productivity effects of ICT are conditional and time-dependent rather than universal.

These traditions intersect productively in the long debate over the Solow productivity paradox. When Solow observed in 1987 that computers were visible everywhere except in the productivity statistics, the puzzle appeared to threaten the entire investment case for ICT. The resolution that has crystallized in the subsequent decades does not dismiss the paradox but reframes it. Brynjolfsson (1993) argued that the disjuncture between visible computing investment and elusive productivity gains reflected four mechanisms operating simultaneously: mismeasurement of digital outputs in national accounts, lags between investment and complementary reorganization, redistribution of gains across firms within an industry rather than to the industry aggregate, and outright mismanagement of complex new systems. Each mechanism survives in the contemporary evidence and continues to shape interpretation. Mismeasurement remains acute for free digital services and platform-mediated output that escape conventional national-accounts categories.

Reorganizational lags continue to explain why firms that merely install ICT realize smaller gains than those that redesign workflows around it, exactly as Bresnahan et al. (2002) later documented at the firm level. The redistribution mechanism implies that aggregate measures can understate the technology's substantial effect at the production-unit level, a caution that bears directly on cross-country panel inference. And mismanagement, taken broadly to include weak managerial practice and insufficient digital skills, reappears in every contemporary study that finds complementary human capital decisive.

3.2. ICT And Labor Productivity In Advanced Economies

Direct empirical work on the ICT-labor productivity link began with the United States and other advanced economies, where measurement infrastructure permitted careful decomposition of growth into capital-deepening, multifactor productivity and labor quality components. Oliner and Sichel (2000) attribute a substantial share of the late-1990s acceleration in United States productivity to ICT capital deepening and to faster multifactor productivity growth in ICT-producing industries; their evidence is detailed and methodologically transparent, and it set the benchmark for subsequent growth-accounting work. Stiroh (2002) extends and qualifies this finding at the industry level, showing that ICT-using industries experienced more pronounced productivity gains than ICT-producing ones, but only after sustained investment had accumulated.

European evidence converges on a comparable pattern with a lag. Timmer and van Ark (2005) document that ICT contributed less to European than to United States productivity growth during the 1995-2003 acceleration, attributing the gap to slower ICT-using sector dynamism in much of Europe rather than to differences in ICT supply. Cetté et al. (2015) refine this picture for the United States alongside three other advanced jurisdictions (the Eurozone, the United Kingdom and Canada) between 1970 and 2013, identifying a discernible ICT contribution to labor productivity growth that was significantly higher in the United States than elsewhere and that rose markedly in the second half of the 1990s before falling off considerably. The strength of these studies lies in their careful national-accounts foundations and explicit decomposition of contributions; their main limitation is dependence on the integrity of ICT capital deflators, which are sensitive to hedonic adjustments and can vary in cross-country comparability. Elstner et al. (2022) push this strand

further by examining whether digitalization has revived productivity in Germany, finding evidence of selective effects concentrated in particular sectors and firm types rather than a broad-based acceleration.

A connected literature interrogates whether the ICT-productivity nexus persists once the initial diffusion shock has passed. Gordon and Sayed (2020) caution that much of the United States productivity slowdown after 2005 is consistent with a fading of the one-off ICT level effect rather than evidence that digital technologies never mattered; the broader implication is that observed effects depend critically on the period studied. Hsieh and Goel (2019) reinforce this period-sensitivity at the level of United States labor productivity itself, attributing 0.2 to 0.4 percentage points of growth in non-farm labor productivity to Internet use during the 1996-2010 window and documenting that the contribution attenuated as diffusion approached saturation. Banday and Erdem (2024) widen the lens by applying quantile regression to OECD economies between 1996 and 2020, identifying a sizeable positive association between ICT use and labor productivity that varies across the productivity distribution rather than holding uniformly at the mean. Fulgenzi et al. (2024) take the methodology further by analyzing 24 OECD countries through a stochastic production-frontier approach, separating productivity gains attributable to shifts in the frontier itself, to movements towards or away from it, and to convergence dynamics; the analysis also reaffirms ICT as a general-purpose technology that depends on complementary investments before its potential is realized. Van Ark and Pilat (2024) widen the analytical frame to all G20 economies since 1970, distinguishing a leading-but-slowing group, a lagging-but-growing group and a muddling-through group, and showing that the post-2010 productivity slowdown across the bloc is underpinned mainly by lower total-factor-productivity growth rather than weak capital deepening. Together these contributions suggest that advanced-economy evidence is reasonably settled in direction but contested in magnitude, timing and distributional incidence, a pattern that complicates simple transfer of findings to G20 emerging members.

3.3. Heterogeneous Effects Across Countries and Conditions

Studies that pool advanced and developing economies almost uniformly report that ICT effects are uneven, and the conditioning factors fall into a recognizable set. Dewan and Kraemer (2000) provide

influential early evidence that returns to ICT investment differed sharply between developed and developing countries during the 1980s and early 1990s, with positive and significant effects in the former and effectively zero returns in the latter. Subsequent work in the same tradition, particularly Dedrick et al. (2013), refines the picture by introducing explicit thresholds: a critical mass of complementary infrastructure, human capital and institutional quality appears to be necessary before ICT investment yields measurable productivity gains.

Röller and Waverman (2001) anticipate this conditional logic in their analysis of telecommunications infrastructure and economic growth across 21 OECD countries over twenty years, finding a significant positive causal link especially when a critical mass of telecommunications infrastructure is present. Their result is about aggregate growth rather than labor productivity specifically, but it foreshadows the threshold logic that later labor-productivity studies support. Najarzadeh et al. (2014) extend the analysis to Internet use specifically in a cross-country dynamic panel and report a positive but conditional relationship, with effects mediated by the level of economic development. The methodological strength of these studies is their explicit attention to non-linearity, which earlier linear specifications had obscured. Their limitation is that threshold parameters are often estimated with limited precision and prove sensitive to sample composition, making cross-study comparison difficult.

Sectoral and regional heterogeneity adds a second axis of variation. Skorupinska and Torrent-Sellens (2015) analyze 21 Central and Eastern European countries over 1993-2011 and document a considerable gap between the region and the wider European Union in human capital, infrastructure, innovation capacity and institutional quality, with co-innovation processes emerging as a key conditioner of ICT productivity effects. Brynjolfsson (1993) had foreshadowed this pattern by framing the productivity paradox as a problem of mismeasurement and complementary reorganization rather than as evidence that computers did not work; the subsequent empirical literature has largely vindicated that intuition. Harrathi and Alshogheathri (2025) extend the labor-productivity question to the Middle East and North Africa, applying dynamic panel methods to MENA economies and finding that labor productivity responds positively and significantly to changes in Internet use, alongside complementary effects from

auxiliary variables. Salim et al. (2024) supply complementary evidence from the Southeast Asian emerging economies, applying a Two-Way Random-Effects model to an augmented Solow specification and reporting that Internet use and mobile cellular subscriptions exert significant positive effects on labor productivity, with human capital shown to matter as much as physical capital in lifting output per worker. Karacuka et al. (2025) document a sectorally heterogeneous productivity paradox in 40 sub-Saharan African economies, with digitalization showing only a weak association with overall labor productivity but a positive effect in agriculture and manufacturing alongside a negative effect in services, illustrating that conditional and uneven outcomes extend well into the present.

3.4. *ICT And Economic Growth*

A larger empirical strand focuses on aggregate output growth instead of labor productivity per se. Vu (2011) and Farhadi et al. (2012) examine cross-country links between ICT diffusion and growth in samples that variously include G20 members and report broadly positive associations whose strength depends on the level of development and the ICT indicator used. Niebel (2018) provides one of the broadest comparative tests at 59 developed, emerging and developing countries between 1995 and 2010 and finds a positive ICT-growth elasticity whose magnitude does not differ statistically across the three country groups. Arvin et al. (2021) examine the G-20 bloc itself over 1961-2019 and document interdependencies linking ICT diffusion to trade openness, foreign investment and aggregate growth, while Pradhan et al. (2022) examine ICT infrastructure and growth specifically in G-20 countries using ARDL modeling and report mixed evidence whose direction and magnitude vary across indicators. Jangid et al. (2024) extend the G-20 evidence with a panel ARDL analysis covering both the bloc and the role of complementary digital and financial-inclusion variables, finding a discernible positive effect of digitalization on growth that survives controls for population and gross fixed capital formation. Bakry et al. (2023) apply a nonlinear panel ARDL to 27 ICT-leading economies and report asymmetric ICT effects on both economic growth and energy consumption, with reductions in ICT use carrying severe long-run growth costs.

The collective strength of this strand is breadth: it covers many countries, periods and methods, and provides a stable general impression of a positive but heterogeneous ICT-growth association. Its limitation, from the perspective of this review, is that aggregate

growth is a noisier outcome than labor productivity. Growth blends capital accumulation, labor supply changes, terms-of-trade shifts and productivity in ways that obscure the specific mechanism through which ICT operates on working people. Treating growth and labor productivity as interchangeable, as some studies effectively do, conflates outcomes that the underlying theory distinguishes carefully. This gap is particularly consequential for G20 analysis, where labor-productivity dynamics differ markedly between advanced and emerging members even when growth rates are comparable.

3.5. ICT, Financial Development and Trade

A subset of the literature situates ICT within broader development processes by modeling its interaction with financial deepening and trade integration. Pradhan et al. (2018) exploit a cross-country panel and use causality analysis to show that ICT infrastructure, financial development and economic growth interact in mutually reinforcing ways, suggesting that the productivity payoff of ICT depends partly on the depth of the financial system through which complementary investment is intermediated. Bakry et al. (2023) extend this argument with a nonlinear panel ARDL applied to 27 ICT-leading economies and document asymmetric effects of ICT changes on both growth and energy consumption, with reductions in ICT use carrying disproportionate long-run costs. Arvin et al. (2021), already discussed in connection with G-20 growth, supply the trade-and-investment lens by documenting interdependencies among ICT diffusion, trade openness, foreign direct investment and growth across the bloc.

These contributions enrich the picture by showing that ICT does not operate in isolation; the institutional and economic context determines whether its effects compound through financial channels and trade integration or remain narrowly confined to direct capital deepening. The methodological strength of this strand is its explicit modeling of mediating channels; its weakness is that channel identification typically requires strong assumptions about exogeneity that empirical work cannot always defend, leaving the precise share of the ICT effect attributable to each channel uncertain.

3.6. Macro And Policy Framing

Recent macro-policy work places ICT within the wider productivity slowdown and recovery debate. The International Monetary Fund (2024) frames the productivity puzzle in advanced economies as a multi-factor problem in which digitalization is one

driver among several. Cetté et al. (2015), Elstner et al. (2022), Borowiecki et al. (2023) and Banday and Erdem (2024) supply complementary national and regional perspectives that highlight the difficulty of attributing post-2010 productivity trends to any single factor. Adarov et al. (2022) reinforce this picture by documenting how digital and intangible capital, foreign direct investment and trade integration jointly shape productivity outcomes, with effects whose strength varies across sectors and country groups. Blomström et al. (1998) and Cohen and Levinthal (1990) provide earlier conceptual anchors on how technology, openness and absorptive capacity interact, and remain relevant for thinking about why G20 members differ. Myrdal (1957) and Dunning (1988), though older, supply the development-economics and international-investment lenses that help explain why technology transfer is uneven across the bloc.

Read together, these strands suggest that ICT belongs in the productivity discussion but cannot bear the explanatory weight alone. The strength of this macro-policy literature is its breadth and integration of multiple drivers; its limitation is that synthesis tends to be qualitative rather than tightly identified, which leaves the precise magnitude of ICT contributions open. For the G20 specifically, the macro-policy framing has been applied unevenly, with detailed studies for several advanced members but sparser coverage of large emerging economies whose digital transitions are still under way.

3.7. Sectoral Evidence: Manufacturing, Services and Agriculture

A consistent finding across studies that disaggregate by sector is that the ICT-productivity link operates with different strengths and through different mechanisms depending on the production technology in which it is embedded. Stiroh (2002) documents at the United States industry level that gains accrue most rapidly to ICT-using industries, particularly in services, where the technology can reconfigure customer-facing processes, logistics and information flows in ways that manufacturing investments often cannot replicate at comparable speed. Skorupinska and Torrent-Sellens (2015) reach a compatible conclusion for Central and Eastern European economies, where co-innovation between ICT investment and complementary intangible assets emerges as the channel through which productivity gains materialize unevenly across sectors. The pattern that connects these advanced and transition-economy findings is that ICT's productivity impact is mediated by the malleability of the underlying

production process, and that sectors organized around information handling realize gains earlier and more visibly than sectors organized around physical transformation.

Recent evidence from emerging economies reinforces this asymmetry while also reversing it in important respects. Karacuka et al. (2025) provide one of the cleanest sectoral decompositions for an emerging-economy sample, examining 40 sub-Saharan African economies between 2006 and 2021 and finding a positive digitalization-productivity link in agriculture and manufacturing but a negative effect in services, the opposite of the advanced-economy pattern documented by Stiroh. The interpretation that best reconciles these findings is institutional rather than technological: where service sectors are dominated by informal activity, low-margin retail and limited formal-sector employment, the introduction of digital intermediation can displace rather than augment labor, generating measured productivity declines even as the technology spreads. Zhu et al. (2024) sharpen the agricultural channel with household-level micro evidence from China, showing that ICT adoption raises farmers' agricultural income and labor productivity primarily by reducing transaction costs in information access; the micro mechanism documented at the household level helps explain why aggregate sectoral coefficients for agriculture tend to be positive in emerging-economy samples even when service-sector coefficients are not. Laddha et al. (2022) report compatible cross-country evidence from a 98-country panel covering 2000-2015, where telephone and broadband subscriptions raised overall and service-sector labor productivity significantly, a result that shows how directly the choice of ICT proxy shapes apparent sectoral conclusions and cautions against drawing aggregate inferences from any single indicator.

The implication for G20 analysis is that aggregate national estimates risk masking offsetting sectoral effects that move in opposite directions. An economy with rapid ICT-driven gains in manufacturing and contemporaneous losses in services may register a muted aggregate coefficient that misrepresents the underlying productivity dynamics, and the same numerical estimate could mean very different things in different members of the bloc depending on which sectors dominate. The methodological strength of sectoral studies is precisely this disaggregation; their main limitation is data availability, with consistent sectoral series on ICT use and labor productivity remaining sparse across emerging G20 members and especially scarce for the services and agricultural

categories where institutional mediation matters most. Future G20 work would benefit from sectoral decomposition wherever the data permit, given that policy levers, complementary investments and institutional reforms differ across manufacturing, services and agriculture in ways that aggregate estimates cannot capture.

4. RESULTS AND DISCUSSION

Three patterns emerge consistently from the literature reviewed above. The direction of the ICT-productivity relationship is reasonably stable: across samples, periods and methods, ICT diffusion is associated with higher labor productivity in the large majority of reported estimates, with negative coefficients clustering in specific post-crisis sub-periods rather than overturning the general pattern. The magnitude, however, is unstable in a way that is itself informative. Effects are systematically larger in advanced economies and ICT-intensive sectors, weaker or statistically fragile in less developed contexts, and conditional on human capital, institutional quality and the maturity of diffusion. The threshold findings of Röller and Waverman (2001) and Dedrick et al. (2013), and the persistent paradox documented by Karacuka et al. (2025), are not contradictions but expressions of the same conditional logic: ICT pays off where complementary investments have accumulated, and disappoints where they have not.

Timing constitutes a third organizing principle. The acceleration episodes identified by Oliner and Sichel (2000), Timmer and van Ark (2005), Cetté et al. (2015) and Elstner et al. (2022) concentrate in a roughly decade-long window in advanced-economy data and then attenuate, consistent with a powerful level effect rather than a permanent change in the growth rate; this temporal pattern may not generalize directly to emerging G20 members at earlier diffusion stages. Gordon and Sayed (2020) and van Ark and Pilat (2024) develop the implication that interpretation of more recent productivity data must be cautious about generalizing from this finite episode. The conditional and temporally bounded nature of the ICT effect is itself a stable finding, and apparent contradictions in the literature largely dissolve once differences in the ICT proxy, outcome variable, sample composition and time horizon are recognized explicitly.

A clear asymmetry of evidence also stands out for the G20. Studies of the bloc overwhelmingly model growth rather than labor productivity, and few span the full diffusion cycle from early take-up to maturity. Pradhan et al. (2022) examine G-20

economies directly but report mixed evidence whose direction varies across indicators; Bakry *et al.* (2023) and Harrathi and Alshogeathri (2025) provide cross-country or regional evidence whose G20 representation is partial; Jangid *et al.* (2024) reinforce the G-20 panel-ARDL evidence on the digitalization-growth channel; and van Ark and Pilat (2024) offer the most G20-targeted productivity analysis to date, distinguishing leading, lagging and muddling-through sub-groups within the bloc. The synthesis can therefore describe the general shape of the ICT-productivity relationship with reasonable confidence, while remaining unable to specify its parameters for G20 economies on the most appropriate outcome measure across the full period during which Internet use diffused. This asymmetry is the central evidentiary gap that motivates further research on the bloc.

Several theoretical frameworks help interpret these patterns. The general-purpose-technology view (Bresnahan & Trajtenberg, 1995; Bresnahan *et al.*, 2002) explains why effects accrue chiefly to economies and firms that reorganize around ICT rather than those that merely install it. Absorptive-capacity reasoning (Cohen & Levinthal, 1990) clarifies why thresholds in human capital and institutional quality matter so persistently. Diffusion-of-innovations theory (David, 1990) accounts for the temporal arc, including the lag between technological availability and broad productivity effects. Together these frameworks suggest that conflicting empirical findings reflect differences in where each sample sits along the underlying conditional and temporal distribution, not deep disagreement about whether ICT matters.

The policy implications for G20 economies follow from this conditional logic rather than from any single point estimate. Where complementary investments are mature, additional ICT capital is likely to yield diminishing rather than expanding marginal returns; the policy lever shifts towards organizational practice, skill upgrading and platform-economy regulation. Where complementary investments are still being accumulated, ICT infrastructure investment remains productive, but pairing it with human-capital and institutional reform is essential to realize the gains the advanced-economy experience suggests are possible. The literature thus implies a differentiated policy stance across the G20 rather than a uniform digital-investment prescription, and this differentiation is precisely what an aggregate growth-focused literature obscures.

The G20 itself contains this policy-relevant

heterogeneity in microcosm. Advanced members (the United States, the United Kingdom, Germany, France, Italy, Japan, Canada, Australia and Republic of Korea) sit close to or at the saturation phase of basic Internet diffusion, with complementary investments largely accumulated and with policy attention turning towards platform regulation, data governance, artificial-intelligence diffusion and the upgrading of digital skills at the upper tail of the labor distribution. Emerging members (China, India, Indonesia, Brazil, Mexico, Argentina, Russian Federation, Turkey, Saudi Arabia and South Africa) span a wider range of diffusion stages, with Internet penetration still expanding in several and with the policy frontier including basic infrastructure, digital-skill formation at the broader population level, and the construction of institutional environments capable of capturing the technology's productivity returns. Treating the bloc as if a single ICT-productivity coefficient applied to all members understates this dispersion and is likely to mislead both inference and policy advice.

The conditional logic identified throughout the literature also indicates where the most productive policy interventions are likely to lie. For mature digitalizers, the binding constraint is rarely the quantity of digital capital but the depth of complementary investments in management practice, organizational redesign and high-end skill formation; their policy priority shifts from infrastructure to governance and to interventions that accelerate productivity-enhancing reorganization in the spirit of the Brynjolfsson-Bresnahan firm-level evidence. For emerging digitalizers, the analysis points to the joint pursuit of three reinforcing tracks: closing remaining infrastructure gaps where they persist, building absorptive capacity through education and managerial-skill upgrading, and ensuring that institutional quality is adequate to support the reallocation of resources that productivity gains require. The policy lesson that emerges is not that ICT investment should be slowed or accelerated in any uniform way across the G20 but that its productivity payoff is contingent on the rest of the development package, and that ignoring these contingency invites either disappointment in slow adopters or complacency in mature ones.

5. CONCLUSION

This review consolidates a fragmented body of evidence on ICT diffusion and labor productivity into a coherent account organized around mechanism, country coverage and method. The

central finding is that the ICT-productivity relationship is positive in direction but conditional and time-bounded in magnitude. Effects depend on human capital, institutional quality and the stage of diffusion, are larger in advanced economies and ICT-intensive sectors, and concentrate in a finite window before attenuating. Apparent contradictions in the literature reflect differences in measurement, outcome choice, sample composition and time horizon rather than substantive disagreement about whether ICT matters.

The review also exposes three specific limitations of the existing literature on G20 economies. First, most G20 studies model economic growth rather than labor productivity, conflating outcomes that the underlying theory carefully distinguishes. Second, few studies observe the full diffusion cycle from early take-up through maturity, leaving open whether documented effects generalize as Internet use approaches saturation in advanced members and continues to expand in emerging ones. Third, estimation strategies in cross-country panels of G20 members frequently underplay cross-sectional dependence and heterogeneity across members at different stages of digital transition, which can bias both magnitude and inference.

Three priorities for future research follow directly from these gaps. First, future empirical work on the G20 should target labor productivity directly, defined as output per worker on a comparable basis, rather than aggregate growth, so as to isolate the channel through which ICT reaches working people. Second, the temporal scope of analysis should span both the growth and maturity phases of Internet diffusion, ideally covering the period from the late 1990s to the most recent year for which comparable data exist, so that the full conditional and temporal profile becomes observable. Third, estimation strategies should accommodate cross-sectional dependence across G20 members and heterogeneity in adjustment dynamics between advanced and emerging members, using methods that have become standard in the wider panel-data literature but remain underused in G20-specific analyses of ICT.

Beyond the empirical synthesis, this review contributes to theoretical understanding of the ICT-productivity relationship in three respects. It shows that the apparent fragmentation of the literature dissolves once the conditional logic shared by endogenous growth theory, the general-purpose-technology framework and absorptive-capacity reasoning is treated as the unifying lens; what reads as disagreement in individual studies often reflects different positions along the same underlying

conditional surface. It clarifies why aggregate growth and labor productivity should not be used interchangeably: the underlying theoretical traditions distinguish them carefully, and the empirical evidence suggests that they respond to ICT through partially distinct channels, particularly when capital accumulation and labor-supply dynamics move in offsetting directions. And it positions the productivity paradox as a recurring diagnostic phenomenon, not a historical curiosity of the 1980s and 1990s. Its recent expression in sub-Saharan Africa, in selected European economies and in post-pandemic recovery data calls for the same conceptual tools that Brynjolfsson (1993) and David (1990) developed for earlier episodes. These contributions are conceptual rather than quantitative, but they provide the scaffolding within which a more targeted G20-specific empirical program can productively proceed.

The contribution of this review is, accordingly, threefold. It shows that the apparent inconsistency of ICT-productivity findings follows a single conditional logic once measurement and design differences are taken into account. It isolates three specific gaps in the G20 literature, in outcome choice, time horizon and estimation strategy, that together define a focused research agenda. And it provides the theoretical scaffolding, drawing on endogenous growth, general-purpose-technology, absorptive-capacity and diffusion-of-innovations traditions, within which future G20-specific evidence can be interpreted coherently. The conditional nature of the ICT effect is, in the end, neither a disappointment nor an artifact: it is the substantive finding, and the question for future work is how reliably its parameters can be estimated for the G20 across the full period during which the digital transition has unfolded.

6. RECOMMENDATIONS

Three recommendations follow directly from the synthesis above and are addressed to researchers planning the next generation of G20-focused empirical work. First, future studies should measure labor productivity directly, defined as output per worker on a comparable cross-country basis, rather than substituting aggregate growth as a proxy; the two outcomes respond to ICT through partially distinct channels and conflating them obscures the mechanism that matters most for living standards. Second, empirical designs should distinguish explicitly between advanced and emerging G20 members and between diffusion stages, recognizing that the same numerical coefficient can carry very

different policy meanings in countries at different points along the conditional and temporal surface identified throughout this review. Third, estimation strategies should adopt diagnostic-driven panel methods that account for cross-sectional dependence and heterogeneity across G20 members, including second-generation unit-root tests, error-correction or cointegration approaches where the data support

them, and explicit treatment of structural breaks; these methods are standard in the wider panel-data literature but remain underused in G20-specific analyzes of ICT. Acting on these three recommendations would allow future work to specify, rather than merely describe, the ICT-labor productivity relationship for the bloc most central to global productivity outcomes.

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REFERENCES

- Adarov, A., Klenert, D., Marschinski, R., & Stehrer, R. (2022). Productivity drivers: Empirical evidence on the role of digital and intangible capital, FDI and integration. *Applied Economics*, 54(48), 5515–5531. <https://doi.org/10.1080/00036846.2022.2047598>
- Arvin, M. B., Pradhan, R. P., & Nair, M. (2021). Uncovering interlinks among ICT connectivity and penetration, trade openness, foreign direct investment, and economic growth: The case of the G-20 countries. *Telematics and Informatics*, 60, 101567. <https://doi.org/10.1016/j.tele.2021.101567>
- Bakry, W., Nghiem, X.-H., Farouk, S., & Vo, X. V. (2023). Does it hurt or help? Revisiting the effects of ICT on economic growth and energy consumption: A nonlinear panel ARDL approach. *Economic Analysis and Policy*, 78, 597–617. <https://doi.org/10.1016/j.eap.2023.03.026>
- Banday, T. P., & Erdem, E. (2024). ICT and declining labor productivity in OECD. *SN Business & Economics*, 4(3), Article 33. <https://doi.org/10.1007/s43546-024-00626-5>
- Becker, G. S. (1975). *Human capital: A theoretical and empirical analysis, with special reference to education* (2nd ed.). National Bureau of Economic Research.
- Blomström, M., & Kokko, A. (1998). Multinational corporations and spillovers. *Journal of Economic Surveys*, 12(3), 247–277. <https://doi.org/10.1111/1467-6419.00056>
- Borowiecki, M., Giovannelli, F., & Hoj, J. (2023). COVID-19 and productivity-enhancing digitalisation: Firm-level evidence from Slovenia. *OECD Economics Department Working Papers*, No. 1766. <https://doi.org/10.1787/5f7e9340-en>
- Bresnahan, T. F., Brynjolfsson, E., & Hitt, L. M. (2002). Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence. *The Quarterly Journal of Economics*, 117(1), 339–376. <https://doi.org/10.1162/003355302753399526>
- Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies: 'Engines of growth'? *Journal of Econometrics*, 65(1), 83–108. [https://doi.org/10.1016/0304-4076\(94\)01598-T](https://doi.org/10.1016/0304-4076(94)01598-T)
- Brynjolfsson, E. (1993). The productivity paradox of information technology. *Communications of the ACM*, 36(12), 66–77. <https://doi.org/10.1145/163298.163309>
- Cette, G., Clerc, C., & Bresson, L. (2015). Contribution of ICT diffusion to labour productivity growth: The United States, Canada, the Eurozone, and the United Kingdom, 1970–2013. *International Productivity Monitor*, 28, 81–88.
- Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128–152. <https://doi.org/10.2307/2393553>
- David, P. A. (1990). The dynamo and the computer: An historical perspective on the modern productivity paradox. *The American Economic Review*, 80(2), 355–361.
- Dedrick, J., Kraemer, K. L., & Shih, E. (2013). Information technology and productivity in developed and developing countries. *Journal of Management Information Systems*, 30(1), 97–122. <https://doi.org/10.2753/MIS0742-1222300103>
- Dewan, S., & Kraemer, K. L. (2000). Information technology and productivity: Evidence from country-level data. *Management Science*, 46(4), 548–562. <https://doi.org/10.1287/mnsc.46.4.548.12057>
- Dunning, J. H. (1988). The eclectic paradigm of international production: A restatement and some possible extensions. *Journal of International Business Studies*, 19(1), 1–31. <https://doi.org/10.1057/palgrave.jibs.8490372>
- Elstner, S., Grimme, C., Kecht, V., & Lehmann, R. (2022). The diffusion of technological progress in ICT. *European Economic Review*, 149, 104277. <https://doi.org/10.1016/j.euroecorev.2022.104277>
- Farhadi, M., Ismail, R., & Fooladi, M. (2012). Information and communication technology use and economic growth. *PLoS ONE*, 7(11), e48903. <https://doi.org/10.1371/journal.pone.0048903>
- Fulgenzi, R., Gitto, S., & Mancuso, P. (2024). Information and communication technology and labour productivity growth: A production-frontier approach. *Annals of Operations Research*, 333, 123–156. <https://doi.org/10.1007/s10479-024-05818-8>
- Gordon, R. J., & Sayed, H. (2020). Transatlantic technologies: The role of ICT in the evolution of US and European productivity growth. *International Productivity Monitor*, 38, 50–80.
- Harrathi, N., & Alshogeathri, M. A. (2025). Sensitivity of labor productivity to Internet use: The case of MENA countries. *Journal of the Knowledge Economy*. Advance online publication. <https://doi.org/10.1007/s13132-025-02735-4>
- Hsieh, E. W.-T., & Goel, R. K. (2019). Internet use and labor productivity growth: Recent evidence. *Netnomics*:

- Economic Research and Electronic Networking, 20, 195–210. <https://doi.org/10.1007/s11066-019-09135-2>
- International Monetary Fund. (2024). G20 report on strong, sustainable, balanced, and inclusive growth. International Monetary Fund. <https://www.imf.org/-/media/Files/Research/imf-and-g20/2024/g20-report-2024-on-strong-sustainable-balanced-and-inclusive-growth.ashx>
- Jangid, H., Bal, D. P., & Debata, B. (2024). Digitalisation and economic growth in G-20 countries: A panel ARDL analysis. *Journal of Technology Management & Innovation*, 19(4), 18–30.
- Karacuka, M., Myovella, G., & Haucap, J. (2025). Productivity paradox in Africa: Does digitalization foster labor productivity in African economies? *Journal of the Knowledge Economy*, 16(2), 8374–8393. <https://doi.org/10.1007/s13132-024-02200-8>
- Laddha, Y., Tiwari, A., Kasperowicz, R., Bilan, Y., & Streimikiene, D. (2022). Impact of information communication technology on labor productivity: A panel and cross-sectional analysis. *Technology in Society*, 68, 101878. <https://doi.org/10.1016/j.techsoc.2022.101878>
- Lucas, R. E., Jr. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, 22(1), 3–42. [https://doi.org/10.1016/0304-3932\(88\)90168-7](https://doi.org/10.1016/0304-3932(88)90168-7)
- Myrdal, G. (1957). *Economic theory and under-developed regions*. Duckworth.
- Najarzadeh, R., Rahimzadeh, F., & Reed, M. (2014). Does the Internet increase labor productivity? Evidence from a cross-country dynamic panel. *Journal of Policy Modeling*, 36(6), 986–993. <https://doi.org/10.1016/j.jpolmod.2014.10.003>
- Niebel, T. (2018). ICT and economic growth: Comparing developing, emerging and developed countries. *World Development*, 104, 197–211. <https://doi.org/10.1016/j.worlddev.2017.11.024>
- Oliner, S. D., & Sichel, D. E. (2000). The resurgence of growth in the late 1990s: Is information technology the story? *Journal of Economic Perspectives*, 14(4), 3–22. <https://doi.org/10.1257/jep.14.4.3>
- Pradhan, R. P., Mallik, G., & Bagchi, T. P. (2018). Information communication technology (ICT) infrastructure and economic growth: A causality evinced by cross-country panel data. *IIMB Management Review*, 30(1), 91–103. <https://doi.org/10.1016/j.iimb.2018.01.001>
- Pradhan, R. P., Sarangi, A. K., Maity, C., & Behera, R. R. (2022). ICT infrastructure and economic growth in G-20 countries: New insights form ARDL modelling. *The Journal of Developing Areas*, 56(1), 47–58. <https://doi.org/10.1353/jda.2022.0009>
- Röller, L.-H., & Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *The American Economic Review*, 91(4), 909–923. <https://doi.org/10.1257/aer.91.4.909>
- Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5, Part 2), S71–S102. <https://doi.org/10.1086/261725>
- Salim, A., Wen, J., Bello, A. U., Lubis, F. R. A., Khoirudin, R., Khasanah, U., Sukarniati, L., & Nasir, M. S. (2024). Does information and communication technology improve labor productivity? Recent evidence from the Southeast Asian emerging economies. *Growth and Change*, 55(1), e12708. <https://doi.org/10.1111/grow.12708>
- Skorupinska, A., & Torrent-Sellens, J. (2015). The role of ICT in the productivity of Central and Eastern European countries: Cross-country comparison. *Revista de Economia Mundial*, 39, 201–222.
- Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, 70(1), 65–94. <https://doi.org/10.2307/1884513>
- Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, 39(3), 312–320. <https://doi.org/10.2307/1926047>
- Stiroh, K. J. (2002). Information technology and the U.S. productivity revival: What do the industry data say? *The American Economic Review*, 92(5), 1559–1576. <https://doi.org/10.1257/000282802762024638>
- Timmer, M. P., & van Ark, B. (2005). Does information and communication technology drive EU-US productivity growth differentials? *Oxford Economic Papers*, 57(4), 693–716. <https://doi.org/10.1093/oep/gpi032>
- van Ark, B., & Pilat, D. (2024). Productivity drivers and pro-productivity policies: G20 economies, India and South Korea. *Indian Economic Review*, 59(Suppl 1), S95–S121. <https://doi.org/10.1007/s41775-024-00230-2>
- Vu, K. M. (2011). ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 period. *Telecommunications Policy*, 35(4), 357–372. <https://doi.org/10.1016/j.telpol.2011.02.008>

Zhu, Q., van der Voort, M., de Mey, Y., & Bai, J. (2024). How can information and communication technologies influence farmers' agricultural income and labor productivity? Micro evidence from China. *Applied Economics*. Advance online publication. <https://doi.org/10.1080/00036846.2024.2386845>