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The Role of Information and Communication Technologies in Economic Development

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Abstract

The diffusion of information and communication technologies (ICTs) and their potential as a development tool have generated a wide array of views. The variety of views suggests that the role and impact of these technologies are still obscure and that the debate regarding them suffers from a lack of unambiguous evidence. Recognizing the need for clarity, the author endeavors in this paper to answer three questions: first, what features distinguish these technologies from those invented in the past; second, what are the channels through which ICTs are expected to promote development, and finally, what justifies the confidence placed in ICTs as a development tool, that is, is there empirical evidence supporting the claims made for or against the use and spread of these technologies?

Kurzfassung

Die Verbreitung und Anwendung neuer Informations- und Kommunikationstechnologien (IKT) und die Potentiale, die ihnen in sozioökonomischer Hinsicht zugesprochen werden, haben eine Reihe verschiedener Ansichten über deren tatsächliche Auswirkungen hervorgebracht. Analysiert man diese Meinungen, wird deutlich, daß die Mechanismen, die IKT auslösen, noch nicht hinreichend bekannt sind und es an zweifelsfreien Befunden mangelt. Vor dem Hintergrund dieses Mangels versucht der Autor, die folgenden drei Fragen zu beantworten: Erstens, welche Eigenschaften unterscheiden die IKT von denjenigen Technologien, die in der Vergangenheit hervorgebracht wurden? Zweitens, auf welche Weise können IKT zu Entwicklung beitragen? Und schließlich stellt sich die Frage, inwiefern das Vertrauen, das viele Experten den Technologien entgegenbringen, bislang empirisch untermauert werden konnte.

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1 Introduction

The development and spread of information and communication technology (ICT)[1] is often touted as the harbinger of a new industrial revolution. In a strategy piece, Talero and Gaudette (1995) point out that the diffusion of information technologies to all areas of human activity is accelerating change in economies and societies. They go on to state that these changes are creating a new economy – an information economy – in which information is the critical resource and basis for competition. Similar statements by donor agencies and international organizations suggest that the propogation and accessibility of these new technologies should be viewed as an integral element of a country's development strategy (Morales-Gomez and Melesse, 1998).

Notwithstanding these views, and the increasing diffusion of ICTs, their role in promoting economic growth and development is not viewed unambiguously. Views on the usefulness of these technologies range from wild optimism about the opportunities they create to deep pessimism about the possibilities developing countries' have to exploit these technologies to their benefit (Avgerou, 1998).

The former view, stresses the importance of "knowledge or information gaps" as a development constraint and asserts that the provision of these new technologies will help bridge the North-South gap (Kenney, 1995; Moyo, 1996). Proponents attribute a wide and almost impossible array of positive effects to ICTs. For instance, it is argued that by bridging the information gap, the spread of ICTs will accelerate growth, increase agricultural and industrial productivity, increase the efficiency of public administration and the effectiveness of economic reforms, strengthen the competitiveness of developing countries and encourage greater public participation and democracy (Kenney, 1995; Braga, 1996; Hadden, 1996).[2] Despite these claims, it must be noted that the benefits of ICTs are often held to be true axiomatically. Usually, however, the manner in which ICTs lead to such positive effects is not described very clearly.

1 Hamelink (1997) provides the following definition for the range of technologies that fall under the rubric of information and communication technologies. Information and communication technologies encompass all those technologies that enable the handling of information and facilitate different forms of communications among human actors, between human beings and electronic systems, and among electronic systems. These technologies can be sub-divided into capturing, storage, processing, communications and display technologies.

2 ICTs are often identified as "leapfrogging" technologies. Despite the skepticism often associated with this term, Negroponte (1998), believes that these technologies will not fail in delivering the required impetus. Some evidence on this trend is already emerging. According to the World Development Report (1998), telephone networks in Djibouti, the Maldives, Mauritius, and Qatar are fully digitized. In contrast, many industrialized countries continue to rely heavily on older, analog technology.

On a more skeptical note, Rodgers (1995) points out that access to the new technologies is largely a function of the existing education, income and wealth distributions. It is argued that both, the inability to access due to limited education or inappropriate language skills and the prevalence of inequalities in access will tend to exacerbate information gaps and thus increase inter-personal (inter-regional) income inequality in developing countries. This tendency may be strengthened if the use of ICTs increases the demand for skilled labor. Also, it is feared that, at least in the short run, their introduction in manufacturing and service industries may lead to job redundancies and unemployment (Roche and Blaine, 1996). Finally, and maybe most importantly, developing countries may have other, more pressing investment priorities. Devoting limited resources to ICTs would be difficult to justify, especially if there is only scanty evidence of investment returns.[3]

The variety of views expressed above suggests that the role played by information and communication technologies is still obscure and that the debate concerning it suffers from a lack of convincing evidence and information. While this is somewhat ironic, it is clear that if these new technologies are to command the continued interest of the developing world and justify additional investments, a more convincing demonstration of the returns to these technologies is required.

In view of the need for clarity and additional evidence to justify investments in ICTs, this paper endeavors to answer three questions: first, what characteristics distinguish these technologies from those invented in the past; second, what are the links through which these technologies are expected to exert an influence, and third, what justifies the confidence placed in ICTs as a development tool, i.e., is there any empirical evidence to support the claims made for or against ICTs?

To tackle these issues, section 2 provides a characterization of information and communication technologies. Section 3 outlines a framework that links investments in ICTs to economic outcomes and may be used to guide empirical work and measurement efforts in this area. Section 4 takes stock of what is known about the effects of these technologies on productivity, welfare, and wages, focusing particularly on the methodologies that may be used to assess the impact of ICTs. Section 5 presents concluding observations.

[3] For developed countries, there is an increasing body of evidence that indicates a positive impact of ICTs on firm productivity and individual wages, but, empirical evidence for developing countries is still scarce.

2 Information and Communication Technologies – A Characterization

As discussed above, the spread of ICTs has generated unbridled optimism in some quarters. In this section, these technologies are characterized in order to convey an understanding of their unique qualities.[4]

To fully appreciate the potential of these technologies, it should be noted that there is increasing recognition of the importance of ideas, knowledge and information in the development process (Stiglitz, 1989; Romer, 1993; World Bank, 1998). The assertion that a a knowledge gap is an important determinant of persistent poverty, combined with the notion that developed countries already possess the knowledge required to assure a universally adequate standard of living, suggest the need for policies which encourage greater communication and information flows both within and between countries. One of the best possible ways to achieve this greater interaction is through the use of information and communication technologies.

ICTs are able to serve as information channels due to their ability to support the decoupling of information from its physical repository. It is argued that this separation or decoupling property is the truly revolutionary aspect of these technologies (Evans and Wurster, 1997; Pohjola, 1998). This property allows the immediate transmission of large volumes of information and permits communication independent of the physical movement of individuals. The capability to support information separation is the key attribute underlying the wide range of activities and services offered through ICTs.

This decoupling property allows users access to a body of information and ideas which are non-rival in use and potentially generate large *content-related externalities*.[5] Access to new ideas and knowledge may have far-reaching effects (which are discussed in the next section). Apart from the content-related benefits, there are externalities related to the size of ICT networks. The use of ICT networks is also non-rival in nature, and an increase in network size generates *network externalities*. For example, consider a project that permits e-mail access to additional subscribers.

[4] This survey concentrates largely on the information processing and communicating capabilities of ICTs, rather than on their role in automating production processes. Also, it focuses more on the role of ICTs as an intermediate input or facilitator, rather than on their direct contribution to economic development through the development of the software and/or hardware industries.

[5] While the possibility of decoupling permits access to a body of knowledge, many insights and ideas that generate economic value are of a proprietary nature. In such cases, the role of ICTs in enabling access is limited, and other measures such as trade and foreign direct investment may be the appropriate conduits for disseminating information and knowledge.

New subscribers derive benefits from these services, but so do all other subscribers already connected to the system. The expansion of the system allows all earlier subscribers to communicate and exchange information with new subscribers and vice versa. Thus, the gains that accrue to each subscriber rise with the number of other individuals and organizations that have access to the system.[6]

The decoupling property and externalities of ICTs are further complemented by their *pervasive* nature.[7] The use of ICTs is not restricted to a particular sector of the economy. Their widespread application and the possibility of tailoring them to suit individual, corporate and government needs explain the wide range of potential positive effects attributed to the diffusion of these technologies.

Taken together, these three characteristics of ICTs, i.e., their capability to separate information, their content and size related externalities and their pervasive nature, clearly render ICTs unique.[8] An appreciation of these characteristics and the economy-wide effects they generate permits a greater understanding of the development potential offered by ICTs. In order to consider their potential more clearly, the following section uses the characteristics described here to establish a chain of reasoning linking ICTs to the functioning of organizations, the efficiency and spread of markets, and to institutional change.[9]

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[6] Another externality is generated from the cost perspective. Expanding internet access, or telecommunications services often entails declining average costs over a wide range. Hence, expanding the system leads to a fall in the costs of supplying services to earlier subscribers.

[7] A report published by the OECD (1988) singles out IT as the most pervasive technical innovation of the post-war era. More specifically, according to Avgerou (1998), a technology may have pervasive economic effects if it (i) generates a wide range of new products and services (ii) generates strong industrial interests as a means for profitability and competitive advantage and (iii) reduces the costs and improves the performance of the processes, services and products of many sectors of the economy. While empirical confirmation of the effects of ICTs on performance, especially in developing countries, is still awaited, ICTs certainly qualify and deserve the moniker of pervasive technologies on the basis of the first two criteria.

[8] From a technical standpoint, the unifying characteristic of these technologies is “digitisation.” Hamelink (1997), writes that digitisation is a process through which information (whether relayed through sound, text, voice or image) is converted into the digital, binary language computers use. This process of digitisation facilitates the convergence of ICTs, as, in a technical sense, all digital signals are the same, regardless of whether they encode voice, video, or other data.

[9] It should be noted here that in restricting the focus of this survey, it is not our intention to deny the importance of ICTs as a tool for improving education delivery or their impact in other areas. The reason for restricting the focus is entirely pragmatic.

3 Linking Information and Communication Technologies to Development

Since the 1960s and 1970s, standard neoclassical theory based on the traditional assumptions of costless exchange at market clearing prices has given way to more refined analytical work that investigates, among other phenomena, the causes and consequences of transaction costs, uncertainty, incomplete markets and incomplete information. These developments have provided another perspective, i.e., the information-theoretic approach to understanding LDCs (Stiglitz, 1989).

One of the central tenets of the information-theoretic approach and a feature noted by early observers is that acquiring information is extremely costly, especially within the context of LDCs. For instance, in a discussion of LDC economies, Leibenstein (1968) evokes a picture of LDCs as, "obstructed, incomplete and 'relatively dark' economic systems." A similar sentiment is expressed by Geertz (1978), "information is poor, scarce, maldistributed, inefficiently communicated, and intensely valued." These difficulties associated with information acquisition have numerous implications.

The high costs of acquiring information may lead to behavior that differs markedly from what it would have been if more information had been available. The lack of information may reduce the extent of mutually beneficial exchanges[10] and lead to economy-wide Pareto inefficiencies.[11]

Furthermore, due to information constraints, there will be considerable market and event uncertainty surrounding economic and administrative decisions in LDCs.[12] Both types of uncertainty have implications for the efficiency, productivity, and welfare of the various agents

[10] As Stiglitz (1989) points out, transactions which would be desirable in the presence of perfect information may not occur, and at the same time transactions may occur which would not have occurred in the presence of perfect information. However, the general result is that there is less trade. Also, see Akerlof (1970).

[11] With imperfect information and incomplete markets, the economy is almost always constrained Pareto inefficient, i.e., there exists a set of taxes and subsidies which can make everyone better off (Greenwald and Stiglitz, 1986, 1988).

[12] It may be useful to clarify the differences between market and event uncertainty. Market uncertainty arises when each individual or economic agent is aware of his/her own endowment and productive opportunities, but unsure about the supply-demand offers of other economic agents. This type of uncertainty leads to searches for appropriate partners (resulting in time costs), inhibits exchange and may lead to allocative inefficiencies. In the extreme, when information costs and transaction costs are too high, markets may fail. The second type of uncertainty, event uncertainty, arises when individuals are uncertain not about the terms on which they engage in transactions, but about exogenous events - such as resource endowments (e.g. whether the wheat crop will be large or small), productive opportunities (e.g. whether electricity will be available) or public policy (e.g. whether taxes will be cut).

in the economy, and the appropriate antidote in many cases is to engage in informational activities (see Hirshleifer and Riley, 1992). In this context, the key role of ICTs is that they (are tools that) may be used to acquire and process information and reduce uncertainty. The following section examines the manner in which these technologies may improve the performance of organizations.

3.1 Functioning of organizations

Consider that information costs consist of two components: the cost of gathering and processing information and the cost of distributing information. In developing countries, inadequate communication facilities and high transmission costs reduce the use of existing information and inhibit the production of new information. In such environments, the introduction of reliable and speedy ICTs may have several effects. First, a reduction in the cost of transmitting information will lead to a right-ward shift in the information supply curve, i.e., a reduction in the price and an increase in the transmission of information. Second, since information technology reduces the cost of processing and producing information, there is additional impetus for growth in the supply of information and further reductions in prices. In addition to increasing the quantity of information, the use of ICTs will probably enhance the quality of the available information. Instead of relying on obsolete information, individuals and firms may have access to up-to-date, reliable and more complete information. In a nutshell, the spread of ICTs may facilitate an increase in the availability and quality of information that may be useful for economic and organizational decisions.

The amount of information used by economic agents should satisfy the standard marginal conditions and accordingly, a reduction in the cost of acquiring information should lead to an increase in the amount of information used before economic and administrative decisions are made. The reduction in uncertainty resulting from the use of this additional information should lead to more informed and improved managerial and administrative decision-making.

A key feature of ICTs is that they permit interactive communication and negotiation. This capability to transfer information and communicate around the globe, unhindered by distance, the volume or the nature (video, sound, data) of the information to be transmitted, may lead not only to better, but also to faster decision-making.[13]

Thus, market uncertainty concerns the endogenous variables of the economic system (prices and quantities), and event uncertainty the exogenous data.

[13] In addition to increasing the efficiency of firms, the spread of ICTs may help create new information-intensive firms and industries in developing countries. For instance, high-speed international communication links have enabled India to become a major producer of software. Similarly, exportable-service jobs such as data entry, airline-reservation services and tele-centers for buying various products may be set up in developing countries to provide 24-hour services. While we note these possibilities we do not delve too deeply into this area for the sake of brevity.

A natural corollary of the reduction in information and negotiation costs is that the diffusion of ICTs may promote the efficacy of organizations by enhancing mutually beneficial exchanges. Improved information flows and reduced uncertainty may allow firms to access national and international markets more readily and permit them to open up new product and factor markets. A more detailed discussion of the effect of ICTs on the spread of markets is provided in the following section.

Before proceeding, two additional points need to be made. First, as characterized in the previous section, the effects of these technologies are pervasive. Their role in reducing the cost of information flows and aiding faster and better economic and administrative decision-making is not limited to a particular type of organization. Increased use of these technologies can improve the performance and productivity both of private firms and of public-sector organizations. Talero and Gaudette (1995), argue that public administration is highly information-intensive and that the use of modern IT has the potential to increase the efficiency, transparency and accountability of governments.

Second, the effects of these technologies in reducing uncertainty and leading to quicker and better decision-making should manifest themselves in a variety of ways. At a macro level, the use of ICTs may be expected to enhance the productivity of the various factors of production and should be associated with increases in aggregate output. At a micro level, the use of these technologies should be associated with increases in firm and factor productivity.

3.2 The Functioning and emergence of markets

By lowering the costs of communicating and transmitting information, i.e., by reducing transaction costs, the spread of ICTs may enhance the efficiency and encourage the spread of factor and product markets in developing countries. The potential effects of ICTs on the functioning and spreading of markets may be considered by borrowing a framework used by Norton (1992).[14]

[14] Work on a more complete framework that may be used to estimate transaction costs and to examine whether these costs are the source of reduced market participation is currently underway. This framework will also allow us to examine whether diffusion of ICTs is related to a reduction in transaction costs.

Consider a market with inverse demand and supply functions:

$$P^{+} = a - bQ \tag{1}$$

$$P^{-} = c + dQ, \tag{2}$$

where Q is quantity, P^{+} is the price paid by the buyer, and P^{-} is the price received by the seller. The price gap ($G = P^{+} - P^{-}$) between the buying and the selling price may be defined as the transaction cost.[15] Equilibrium in this market is defined by:

$$Q^* = \frac{a-c-G}{b+d},\ P^{+} = \frac{ad+b(c+G)}{b+d},\ P^{-} = \frac{(a-G)d+bc}{b+d}. \tag{3}$$

As noted before and as shown in (3), a key drawback associated with information deficiency is that it limits the extent of trade and hampers the functioning of markets. In such an environment, a reduction in the cost of acquiring information should lead to an increase in search activity and an increase in the quantity and quality of information that is used prior to decision-making. These increased information flows should, in turn, lead to a reduction in market uncertainty and encourage increased participation in factor and product markets. This effect may be readily seen from the comparative statics $(\frac{\partial Q^*}{\partial G} < 0)$, i.e., a reduction in transaction costs leads to an increase in equilibrium quantity. Note that increased participation in product markets is not restricted to local or national markets. The reduction in transaction costs may make it easier for firms to sell their products nationally and internationally. This feature also applies to factor markets. For instance, as Leff (1984) notes, enhanced information flows and reduced uncertainty may open up new investment opportunities and increase the flow of domestic and international capital.

The impact of readily available and current information may actually be more far-reaching. In many developing countries, the existence of markets can not be taken for granted. For instance, the high degree of self-sufficiency in LDC agriculture seems to indicate that high transaction and information costs may be precluding the emergence of (factor and product) markets. In the framework used here, this feature is readily discernible.

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[15] Several authors have expressed skepticism over the invocation of transaction costs as a means of explaining economic phenomena. Goldberg (1985) points out that appealing to transaction costs as a way of explaining economic phenomena is the all-encompassing answer that tells us nothing. While noting that information costs are an important part of transaction costs, Stiglitz (1989) adopts an information approach citing the lack of specificity of the transaction-costs approach as its main drawback. To avoid these criticisms, here transaction costs are defined on the basis of the simple demand-supply framework used above (see Hirshleifer, 1973; Norton, 1992).

If transaction costs are very high, i.e., G ³ $a - c$, then there is no market participation, and the market fails. As has been pointed out by several authors (see for example Leff, 1984), two key elements that determine the emergence of markets are the costs associated with acquiring information and the cost of negotiating transactions. The spread of ICTs is expected to lead to a reduction in these very costs and accordingly may be expected to exert a positive influence on the emergence of markets.

Thus, two effects may be noted. If markets already exist, then by reducing transactions costs, the spread of ICTs may generate increased market activity. In other words, a narrowing of the price gap (G) may be expected to result in an increase in the equilibrium quantity transacted. Second, by reducing two key prices, the presence of ICTs may be expected to lower the threshold that needs to be overcome for markets to emerge.

3.3 Institutional change [16]

Another tenet of the information-theoretic approach is that many of the special institutional features observed in LDCs have emerged in response to the informational constraints and high transactions costs which pervade these countries.[17] These institutions may thus be regarded as endogenous, and it may be expected that a change in the underlying environment that fosters these institutions will facilitate institutional changes that are more conducive to development.

In this respect, ICTs may provide the impetus for institutional change in two ways. First, the reduction in transaction costs associated with the spread of ICTs may provide the exogenous forces required to create an institutional disequilibrium. This disequilibrium (from the demand or the supply side) could render an existing institutional arrangement less efficient than others in the choice set and provide the impetus required for institutional change. For instance, a phenomenon often observed in third-world agriculture is inter-linked agricultural contracts. In these contracts, the agent is dependent on the principal for several inputs such as land, credit and insurance. While these relationships may reduce aggregate transaction costs, an ICT-induced expansion of markets may reduce the need for such patron-client relationships. Similarly, a reduction in transaction costs and the spread of credit markets may increase the supply of bank credit and reduce the need for the proverbial village money-lender, or the spread of product markets and enhanced information flows may reduce the need for middle-men in the marketing of agricultural produce.

[16] While the term 'institution' may be used in a variety of ways, for the purpose of this survey, a definition borrowed from Lin and Nugent (1995) may be useful. According to them, an institution is defined as a set of humanly devised behavioral rules that govern and shape the interaction of human beings.

[17] For instance, share-cropping may be viewed as a rational response to an incentive problem caused by informational imperfections and a risk problem caused by the absence of insurance markets.

Second, it has been argued that one of the reasons for the persistence of inefficient institutional arrangements is the lack of knowledge about other, more efficient arrangements (Ruttan, 1984; Krueger, 1988). On a similar note, in his research on Africa, Bauer (1984) emphasizes the role of the individual trader in bringing in new technology and knowledge of new institutional arrangements and, as a result, in encouraging people to question existing habits. In this context, by increasing information flows and by allowing access to a body of public knowledge, ICTs have the potential to enlarge the set of institutional choices that may be available to meet a particular need. This increased interaction may spark institutional change by providing greater knowledge of alternative, more efficient arrangements.

3.4 Caveats

In the preceding discussion, it has been argued that the spread of ICTs has the potential to increase the efficiency of organizations, enhance the spread of markets and spark institutional change. However, it must be noted that increased information flows and reduced transaction costs are necessary, but not sufficient conditions for these positive outcomes. If the underlying cause of the inefficiency of organizations or the "thinness" of markets lies not in high transaction costs or market uncertainty but elsewhere, then clearly the spread of ICTs will have only limited effects. Furthermore, it is by no means certain that the institutional changes that are foreseen will actually occur. Competing interests may prevent any change, even when everyone in society is aware that particular institutional arrangements are inefficient and dysfunctional (see Akerlof, 1976).

3.5 Negative effects

Several authors have pointed out the potential negative distributional consequences that may be associated with the diffusion of these technologies. The two major channels through which (the spread of) ICTs may influence income distribution are through their effect on the distribution of information and their effect on employment.

It has been argued that access to ICTs is a function of existing income and wealth distributions and that ICT access will accordingly be limited to a small segment of the population. With such limited access, information gaps and information inequality may be exacerbated and information monopolies may be perpetuated (Saunders, 1983; Morales-Gomez and Melesse, 1998).

While this is a possibility, there is no reason to believe that access to these technologies will be limited to a small segment of the population in every developing country. The distributional outcome in each country/region may differ and will depend on the prevailing policy environment and pattern of allocation of these technologies. In fact, before raising the issue of unequal information access, one must be aware of the situation with which distributional comparisons are being made. In developing countries, access to information is already unequal, and restricting investments on the basis of this argument (i.e., fear of exacerbating informational inequality) will certainly lead to the perpetuation of these inequalities. The policy environment now emerging in several developing countries (marked, for example, by policies allowing private sector participation, and investments in public-use facilities), especially with regard to the more recent information and communication technologies, suggests that these technologies may become more widely diffused. This new environment and the spread of new and cheaper methods of communicating and acquiring information may indeed have ameliorating effects that lead to the attrition of information monopolies and in turn to a more equitable income distribution.

The other channel through which investments in ICTs may have a bearing on income distribution are through their effects on employment. Roche and Blaine (1996) argue that the diffusion of these technologies may increase the demand for skilled labor and render traditional skills and a variety of jobs redundant. A large body of empirical literature has examined whether the recent increases in wage inequality in the US and other developed countries is related to an ICT-induced increase in the relative demand for skilled labor.[18] While it is possible that these technologies may exacerbate wage inequality in some countries, the outcome will probably vary from one country/region to another and will be be determined by the supply of labor and institutional features of the labor market.

Furthermore, it is also possible that the diffusion of these technologies may spark an overall expansion in employment that may increase demand for all types of workers. As pointed out earlier, the expansion of ICTs may be expected to increase the overall and factor productivity of organizations. The increase in the marginal productivity of labor may lead to an increase in employment for all types of labor.[19] Also, if ICTs reduce uncertainty and enhance the efficiency of product and factor markets, their spread may be expected to bring about increases in the flow of capital and in output. The higher employment accompanying these increased investments and output may indeed have a positive effect on income distribution.

[18] A detailed discussion of these papers is provided in the following section.

[19] While it is evident that wage inequality is related to the relative employment of skilled and unskilled workers, it is by no means clear that an economy-wide expansion possibly generated by the diffusion of ICTs will be biased towards more skilled workers.

4 Empirical Evidence

Thus far, the discussion of ICTs' effects on development has been couched in a priori terms. There is, however, an increasing body of literature that examines the effect of these technologies on country growth rates, firm productivity, the spreading of markets, welfare and labor productivity.[20] While these papers usually focus on developed countries, the evidence they provide may contribute to the debate regarding ICTs in developing countries. This evidence is therefore reviewed below.

4.1 Macroeconomic Evidence

Macroeconomic studies that try to evaluate the benefits of information and communication technologies (ICTs) relate measures of the availability of these technologies to measures of national aggregate activity, such as GDP. Studies in this genre usually rely on panel data (information from several countries over a certain time period) and utilize an empirical framework motivated by a production function such as,

$$Y_{it} = f(K_{it}, L_{it}, I_{it}, A_{it}) \qquad (4)$$

where for country i and time period t, Y, K, L and I are GDP, capital, labor, and a measure of ICT infrastructure, respectively, and A is an overall efficiency factor which captures the level of technology. Differentiating (4), yields a growth-accounting equation

$$\dot{Y}/Y = h_1(\dot{K}/K) + h_2(\dot{L}/L) + h_3(\dot{I}/I) + h_4(\dot{A}/A), \qquad (5)$$

where h represents the income share of an input (elasticities in the regression context) and the product $h_4(\dot{A}/A)$ represents multifactor productivity (the productivity residual in a regression context).[21] Empirical specifications of (4) and (5) may be used as a basis for analyzing the effects of ICT on the level and growth of GDP, respectively.

[20] In the previous section, it was pointed out that these technologies have the potential to improve the productivity and performance of public-sector agencies. However, this aspect
is not discussed in much detail as the empirical evidence on this front is rather sparse, and what does exist is largely anecdotal. A reading of some of the papers (e.g., Hanna, 1993; Kamel, 1998) that have tried to assess the effect of ICTs on government performance indicates that the effects of these technologies are mixed. In some cases, the introduction of ICTs may have even increased the incidence of corruption (Heeks, 1998a, 1998b).

[21] This neoclassical growth-accounting framework is based on constant returns to scale in production, competitive input markets and the absence of externalities.

At the outset, it is important to note that this single-equation approach entails a few econometric problems. First, estimating one equation with few variables such as capital and labor is far too parsimonious to provide a convincing estimate of the ICT-growth link. There are a myriad of factors that may influence growth, and ignoring them may lead to an overestimate of the effect of ICTs. Second, a single-equation approach fails to account for the potentially endogenous nature of ICTs and growth, i.e., the greater availability of ICTs may lead to higher GDP, but at the same time, higher GDP may lead to greater demand for ICTs. This endogeneity may lead to an overestimate of the effect of ICTs on growth.

4.1.1 Telecommunications and growth

Early work on the effects of ICTs on growth focused on the telecom-growth link and ignored the econometric issues outlined above.[22] However, by demonstrating the strong correlation between telephone density and GDP, these papers drew attention to the potential role of telecommunications and set the stage for more detailed and elaborate analyses. For instance, Hardy (1980) uses data from 15 developed and 45 developing countries for the years 1960 through 1973 and regresses GDP per capita on lagged GDP per capita, lagged telephones per capita, and the number of radios. While the results of the paper support the idea that the greater availability of telephones has a positive effect on GDP, the results must be interpreted cautiously as the paper ignores the two econometric issues outlined above.

A more recent example of this genre is an analysis conducted by Norton (1992). Using data from a sample of 47 countries for the post-WW II period until 1977, the paper investigates the effects of telephone infrastructure on growth rates and also tries to identify the channels through which the availability of this infrastructure leads to growth (i.e. the effect of telephone infrastructure on the mean investment ratio and consequently on income growth). The empirical framework replicates Kormendi and Meguire (1985), but includes an additional variable to capture the telecommunications infrastructure and is specified as,

$$\begin{aligned} Y_i &= a_Y + b'_Y X_i + g_Y d\_57_i + d_Y d\_avg + e_{Y i} \\ I_i &= a_I + b'_I X_i + g_I d\_57_i + d_I d\_avg + e_{I i} \end{aligned} \qquad (6)$$

where for country i, Y is the mean annual rate of growth in gross domestic product for the sample years, I is the mean investment ratio, X is a vector of variables that influence growth (including initial-year per capita income, mean annual population growth, mean money-supply growth, mean growth in the ratio of government spending to output, mean growth in exports as a proportion of output, and mean growth in the rate of inflation), *d_57* is the telephone density (number of telephones per 100 inhabitants) in 1957 and *d_avg* is the mean telephone density over the time period of the sample. Based on the argument that the existence of a developed communications infrastructure reduces transaction costs and promotes greater output, the effects

[22] Early work conducted in the 1960s and 1970s is reviewed in Saunders *et al*. (1983).

of the telecom infrastructure variables on growth are expected to be positive. The inclusion of a more comprehensive set of regressors is designed to reduce the possibility of overestimating the effect of telecom infrastructure on growth. The use of the two infrastructure variables is an attempt to address the endogenous nature of telephone density and growth. Norton argues that a measure of telephone density prevalent during the early years of the sample is less susceptible to endogeneity bias than a variable which captures the mean telephone density during the entire time period.

The results indicate that the two measures of telecom infrastructure are statistically significant and exert positive effects on mean growth rates. For instance, increasing the 1957 telephone density by one standard deviation (9.909) leads to an increase in mean GDP growth of around 0.73 percent. The effect of the average density variable is greater, but potentially more susceptible to reverse causality. The second set of estimates examines the effect of the telecom infrastructure variables on the mean investment-output ratio. Similar to the earlier results, there is a positive impact on the investment ratio, indicating that telecommunications may be reducing transaction costs, increasing the efficiency of investment markets and consequently leading to increased investment levels. Increasing tele-density by one standard deviation leads to an increase in the investment ratio of around 3.5-4.5 percent. An interesting result is that inclusion of the telecom-infrastructure variables appears to raise investments by leading to a decline in the negative effects associated with monetary shocks. This suggests that telecommunications may be boosting investments by reducing event uncertainty.

Despite the consistency of Norton's results and the use of a lagged measure of tele-density, it is not clear that the reported estimates are free of endogeneity bias. Röller and Waverman (1996) tackle this problem in a more explicit manner by specifying a four-equation structural model with an aggregate production function, telecommunications demand and supply functions and a telecommunications production function. Using data from 35 countries for the years 1970 through 1990, they estimate this four-equation system jointly. Country fixed effects are included to control for other growth-inducing characteristics that might be correlated with a given country's telecom infrastructure. Estimates taking these econometric problems into account indicate that tele-density has no impact on growth.[23]

As argued earlier, the use of ICTs generates network externalities (i.e., an increase in the size of a network leads to greater benefits than those obtained by the marginal user). The presence of these externalities suggests that the impact of telecommunications on growth may not be linear, i.e., the effects of these technologies may be greater (or may become perceptible only) when the size of the network has reached a certain threshold.

[23] This result is similar to the broader literature which investigates the impact of public infrastructure on growth. Allowing for the endogenous nature of GDP and infrastructure availability and including fixed effects causes the strong infrastructure-growth link to evaporate (for a survey, see Jimenez, 1995).

To examine this possibility, Röller and Waverman (1996) estimate an additional specification that allows for non-linear effects of telecom density. This specification indicates that, a 10 percent increase in the penetration rate leads to a 2.8 percent increase in GDP and, more interestingly, that a minimum threshold of telecom density (around 24 percent) must be achieved in order to generate growth.

While the robustness and generality of this threshold effect may be questioned, it does suggest that enhancements in telecommunications infrastructure may generate higher growth effects in developed countries (i.e., countries that have achieved the critical threshold) than in developing countries. In addition, given the low telecom density in developing countries (the 1995 average was around 4 percent, i.e., 4 main telephone lines per 100 people; see UNDP, 1998), it appears that marginal improvements in telecom infrastructure may not generate the desired required growth effects. Thus, developing countries may require substantial investments in ICT infrastructure before they can benefit from the growth-generating effects of these technologies.[24]

While Röller and Waverman (1996) account for some of the econometric problems noted earlier, their results are probably influenced by the non-stationary nature of the data. Within the context of the infrastructure-growth debate, Canning (1998) conducts tests to show that log GDP per capita and log tele-density are non-stationary. Thus, regressing the level of GDP on the level of telephone availability will result in regression coefficients that are too small in relation to their standard errors and will lead to incorrect inferences (see Murray, 1994). To guard against such spurious regressions, Granger and Newbold (1974) recommend that regressions among non-stationary variables be conducted as regressions among changes in these variables.

4.1.2 IT investments and growth

While the previous set of studies dealt with the effects of telecommunications on growth, more recent studies have used the neoclassical growth-accounting framework to examine how investments in computers contribute to growth. A representative study of this type is provided by Niininen (1998). The author begins with a standard growth equation and decomposes Finnish economic growth between 1983 and 1996 into portions that may be attributed to capital, labor and multi-factor productivity. Subsequently, this model is augmented to include the effects of IT on growth, i.e., by examining the contribution of the stock of computer hardware, software and computer labor to growth.

[24] This finding reflects the "big-push" argument. Due to scale economies, the lumpiness of investment and the externalities generated by infrastructural investments, substantial investments in infrastructure may be required before there is a payoff. As Rosenstein-Rodan (1964) put it, "a high initial investment in social overhead capital must either precede or be known to be certainly available in order to pave the way for additional more quickly yielding directly productive investments."

The results indicate that, compared to other inputs, IT exerts quite a strong influence on real growth in output. While 11 percent of the net mean annual growth of 2.36 percent may be attributed to capital, almost 8 percent may be attributed to IT investments. This high share of IT in growth may be attributed to the sharp increases in the rate of growth of computer hardware and software. As for the other components, the contribution of labor is negative, while that of multi-factor productivity (MFP) is more than the total growth rate.[25] Niininen's results are similar to those obtained for the United States, where around 9 percent of the mean annual growth of 1.6 percent between 1987 and 1993 may be attributed to IT investments (see Sichel, 1997).

While these results indicate that IT investments contribute quite substantially to growth, it is possible that relaxing the assumptions underlying the neoclassical growth model, i.e., the absence of externalities, constant returns to scale and competitive markets, may substantially change the results. As argued earlier, investments in IT may generate substantial externalities and increase the efficiency of other inputs as well.[26] If this is the case, then part of the effects of IT would be ascribed to the productivity residual. Similarly, even if IT does not generate externalities but simply has a higher marginal product than other capital, then the effects of IT would also be underestimated. In fact, recognizing these problems, in his estimates, Niinien allows for externalities (by allowing for a higher income share of all capital) and higher marginal returns to capital. As may be expected, the contribution of IT to growth increases and now accounts for between 24 and 36 percent of the growth rate. There is a corresponding drop in the contribution of the productivity residual.

A similar paper (Kraemer and Dedrick, 1994), although cast in a regression context, uses data from eleven Asia-Pacific countries for the years 1983 to 1990 to examine the effect of IT investments on GDP growth. While the authors find a positive correlation between the two and seem to interpret their results as evidence of IT-led growth, they recognize that their results may be plagued by an endogeneity bias.

Concluding remarks: Given the variety of factors that may be responsible for growth (omitted variable problems) and the endogeneity of ICTs and output, it is difficult to identify a clear causal mechanism between ICT availability and income measures or to pin down the quantitative impact of the ICT-growth link. Regardless of the causal linkages, it is clear that there is a positive association between ICTs and growth. This association may be mutually reinforcing. While countries experiencing high growth may be investing more heavily in these technologies, these technologies in turn may be providing the potential for future income growth.

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[25] The contributions of the various components to the total annual growth rate of 2.36 percent are: IT - 0.18, capital - 0.26, labor - 0.89 and MFP - 2.81.

[26] Formally, the direct and indirect effects of ICTs (their direct contributions as measurable final products to output and their indirect effects – enhancing the productivity of other inputs) may be represented by rewriting (4) as: $Y_{it} = A(I_{it})\, f(K_{it}, L_{it}, I_{it})$.

Also noteworthy are two other points. First, it appears that a minimum threshold of telephone/ICT density must be reached in order for ICTs to have growth-enhancing effects. Second, the conventional growth-accounting framework may underestimate the effects of ICTs. If these technologies enhance the efficiency of other inputs, then a large part of the contribution of ICTs may be reflected in increases in multi-factor productivity.[27]

4.2 Microeconomic Evidence

This section reviews papers that have examined the effect of ICTs at a micro-level. These include studies that have explored the effect of ICTs on firm productivity, on consumer welfare and on wages (labor productivity). The literature in each of these areas is examined, and a representative example from each genre is discussed in detail.

4.2.1 The effects of ICTs on firm productivity

As outlined in section 3, ICTs may lead to more rapid, better-informed decision-making by decreasing the cost of acquiring and generating information and reducing communication costs. Empirically, the effects of these cost reductions and better decisions should manifest themselves in enhanced firm productivity. Despite huge investments in computers and related technologies, at first glance, the empirical literature, largely based on data from the United States, does not appear to reveal the impact of these technologies on productivity.

Several articles have chronicled the effect of ICTs on productivity in manufacturing (e.g. Morrison and Berndt, 1990; Siegel and Griliches, 1991; Loveman, 1994) and on productivity in the service sector (e.g. Roach, 1991). While acknowledging data problems, almost all of this early literature concluded that these technologies had little or no impact on productivity.

For instance, Baily (1986) and Roach (1991) point out that, in the 1980s, the US economy failed to show the productivity gains expected from investment in information technology. In fact, during this period of rapid increase in IT-use, overall growth in productivity slowed (Landauer, 1995). This slowdown was particularly acute in the services sector, which made the largest investments in IT (representing about 85 percent of all US computer hardware), yet recorded stagnant productivity. Specifically, the service industry invested $750 billion in information technology in the 1980s and recorded an average productivity growth of 0.7 percent, a rate significantly lower than that of the 1970s and much lower than that of the manufacturing sector, which did not invest as heavily in IT (Ives, 1994).

[27] With regard to the efficiency of other inputs, (discussed in the following section), there is some evidence that skilled labor and the use of ICTs complement each other. That is, these technologies are more likely to be used by skilled workers, and the use of these technologies in turn enhances their productivity.

While it may be argued that estimating productivity in the service sector is difficult, similar results were obtained from studies that investigated the effects of these technologies on the manufacturing industry. One of the first studies to provide econometric evidence of the impact of ICTs on manufacturing was a paper by Loveman (1994)[28]. The author used data from 60 business units for the period from 1978 through 1982 to estimate a production function. Loveman found that the contribution of IT capital to output was negligible for almost every sub-sample and specification that he estimated.

Using a broader data set that covered the entire U.S. manufacturing sector during the 1968-1986 period, Morrison and Berndt (1990) estimated a series of production functions. Their results indicated that the net marginal benefits of IT spending were –20 %, i.e. each dollar spent on "high-tech" capital (computers, instruments and telecommunications equipment) increased measured output by 80 cents. They concluded that " ... there is a statistically significant negative relationship between productivity growth and the high tech intensity of capital."

Siegel and Griliches (1991) combined industry and firm data from multiple government sources to examine possible biases in conventional productivity estimates. Using data from the 1980s, the authors find a positive correlation between an industry's level of investment in computers and MFP. The authors avoid a more structural approach due to problems regarding the reliability and the consistency of the data.

The results of these studies fuelled the "productivity paradox", i.e., despite the huge investments in IT, increases in productivity were not forthcoming. In an attempt to understand this puzzle, Brynjolfsson (1992) points out that the results of these papers should not be overstated and that there are several possible explanations for this paradox. First, the data used to estimate these relationships may not be accurate. It is difficult to measure outputs and inputs, and these measurement problems may be particularly acute in the service sector. Conventional statistics fail to take into account improvements in the quality of products or increases in the variety of products which may have resulted from the increase in ICT use. Second, the positive effects of IT on productivity may be experienced (only) after a time lag. The studies discussed above were based on data and IT investments in the 1970s and 1980s.

[28] The working paper was written in 1988, and the paper appeared in a book in 1994.

The complexity and novelty of these new technologies may necessitate a learning period of some length before the positive effects of the technologies become manifest and measurable. Avgerou (1998) suggests that, in terms of the Neo-Schumpeterian theory of long-run business cycles, IT investments represent a new paradigm in production and technology which renders previous knowledge of production obsolete. Accordingly, organizations will become efficient again only after a long period of learning. Associated with this is the view that significant benefits from IT will be achieved only if the technology is used to support fundamental organizational changes. Other possible explanations are that difficulties in identifying the value of information have led to the misallocation of resources and that IT has a redistributive impact, i.e. firms that invest in IT might benefit, but overall industry productivity and output remain unaffected.

In an attempt to reconcile this paradox, recent work has attempted to examine the IT-productivity link using more accurate and comprehensive data from a later time period. For instance, Brynjolfsson and Hitt (1996) use data from 367 large firms for the 1987-1991 period to examine the following questions: (i) Are the output contributions of computer capital and information systems (IS) staff labor-positive? (ii) Do these positive contributions persist after accounting for depreciation and labor expenses?[29] To answer these questions, the authors jointly estimate a system of Cobb-Douglas production functions for each of the years in their sample. The production function is specified as:

$$\ln Q_{it} = b_t + b_j + b_1 \ln C_{it} + b_2 \ln K_{it} + b_3 \ln S_{it} + b_4 \ln L_{it} + e_t , \qquad (7)$$

where *i* indexes the individual firm, *t* is the time subscript ranging from 1987-1991, *j* represents the industrial sector, *Q* is output, *C* represents computer capital, *K* is non-computer capital, *S* is information services (IS) labor and *L* represents all other labor. The *b*'s are coefficients to be estimated, and *e* is the error term.[30]

Several variants of this basic equation are estimated. These alternative specifications relax the cross-equation equality restriction on the coefficients, allow for measurement error and the endogeneity of computer capital and are estimated on the basis of different sub-samples. Regardless of the specification, estimates of the output elasticity of computer capital stock are statistically significant (at least at the 5 % level), and the magnitude of the coefficient ranges from 0.0113 to 0.0435. The effects of IS labor are less robust (i.e. not always statistically significant) and range between 0.007 and 0.0191. Based on estimates from their baseline specification (elasticities of 0.0169 and 0.0178 for computer capital and IS labor, respectively), an additional dollar spent on computer capital is associated with a yearly increase in output of 81 cents, while an additional dollar spent on IS staff is associated with an increase in output of $ 2.62. These figures may be contrasted with the marginal product of non-computer capital, which

[29] These large firms generated 1.8 trillion dollars in output in 1991 and thus represent a substantial proportion of the US economy.

[30] The five-equation system is estimated as an SUR (seemingly unrelated regression) model. A cross-equation equality restriction is imposed on the coefficients. Errors term are allowed to differ and to be correlated across years. The model is estimated using iterated FGLS (feasible generalized least squares).

is around 6-7 percent, and the returns on non-IS/computer labor, which are around \$ 1.07.[31] These results indicate clearly that the effects of IT are positive and quite substantial. To determine whether the net benefits, i.e., those remaining after costs have been subtracted, are positive, the authors assume that the average service life of a computer is three years, thus yielding a net return of 48 percent (81 – 33) on computer investments. For IS staff, the net marginal product is \$1.62 (2.62 – 1). These positive estimates of the net marginal product suggest that further investments in computing technology and in IS staff may be warranted.

The pronounced differences between the results obtained by Brynjolfsson and Hitt (1996) and those obtained by other authors (as discussed above) are remarkable. The authors explain these differences by appealing to their use of detailed firm data and particularly the time period covered by their sample. They suggest that their more recent data incorporates learning effects and changes in business processes that have been instituted in response to the advent of computers. On the basis of their results, the authors conclude that the productivity paradox has disappeared. While it appears a bit premature (on the basis of one paper) to conclude that the puzzle has been resolved, the results of this paper do suggest that more work using higher quality and more recent data may resolve the puzzle.

Some evidence on the link between ICT adoption and firm productivity in developing countries is provided by Lal (1996), who uses data from 59 small and medium-sized manufacturing firms in the electronics/electrical goods industry in northern India to examine the relationship between IT adoption and firm conduct and firm performance. Firm conduct is captured through the skill intensity of the work force, quality consciousness, international orientation and the importance of R & D. Firm performance indicators are profit margins, turnover, exports, labor productivity and wages. On the basis of a discriminant analysis,[32] Lal reports that firms using IT employ a more highly skilled work force, assign greater importance to product quality, invest more in R & D activities and are more export-oriented. However, there appears to be no link between IT use and firm wages or labor productivity. The finding that firms which employ more highly skilled workers are the first to adopt IT, despite there being no difference in labor productivity between IT-using and non-IT-using firms, is similar to findings yielded by work done in the US manufacturing sector (Doms *et al.,* 1997).

[31] The marginal product of an input is calculated by multiplying the output elasticity of the input by the output-input ratio. For example, in the case of computer capital $E_C = b_1$, the marginal product for computers is $MP_C = dQ/dC = (dQ/dC.C/Q)Q/C = E_C.Q/C$.

[32] Discriminant analysis is a method of distinguishing between groups (here, firms that use IT and those that don't) on the basis of their observed characteristics. Roughly, the analysis distinguishes groups such that variance of the discriminating variables is minimised within the groups, while variance is maximized between the groups. Lal prefers this method of analysis as it entails no causal implications.

Concluding remarks: The evidence from the studies reviewed here suggests that there is no guarantee that investments in ICTs will increase firm productivity. There may be a substantial time lag between ICT investments and their effects, if any, on firm performance. The lag also suggests that effective use of these technologies requires worker training and organizational change and restructuring following ICT investments (see Avgerou, 1998; Kramarz, 1998 and references therein). Additionally, rather than increasing firm productivity, these technologies may exert their influence through product-quality improvements or through improved services. An investigation of the links between ICTs and such indicators may provide additional impetus for ICT investments.

4.2.2 Spreading of markets and institutional change

In the previous section, it was argued that, by reducing transaction costs, the propagation of ICTs has the potential to enhance the spreading and development of product and factor markets. Furthermore, it was pointed out that the spreading of markets and the reduction of information monopolies may provide the impetus for institutional change. Anecdotal evidence of the manner in which these technologies increase access to local and international markets, particularly among small manufacturers, is regularly reported in the popular press. Similar findings are reported in the academic literature. For instance, Albert Hirschmann (1967) observed that a credit market for coffee trade developed in Ethiopia following the installation of a long-distance telephone network. The World Development Report (1998, p.61) points out that in rural Costa Rica and the Ivory Coast/Cote d'Ivoire, small farmers use telecommunications to obtain information on international coffee and cocoa prices from the city. In Sri Lanka, small farmers are able to use information acquired through the telephone to sell their crops at 80 to 90 percent of the price obtained in Colombo, substantially more than the 50 to 60 percent they were able to achieve before the service become available. In Nairobi, a small businessman did 35 percent more business after installing phone lines. Similar instances are reported in Saunders *et al*. (1983, p. 19), as well as by a current project that is examining the effect of cellular telephones in Bangladesh (Bayes and von Braun, 1999).

While these findings are promising, it is important to ask whether these technologies have a more widespread effect on market development. In other words, is there more detailed empirical evidence that links the diffusion of these technologies to the efficiency and spread of markets? While there is some evidence from developed countries (Garbade and Silber, 1978; Du Boff, 1980), detailed studies that have examined the influence of ICTs on the spread and efficiency of markets in developing countries appears to be limited.

Rather than examining the effect of these technologies on markets or some other specific outcomes, an alternative is to examine their effects on welfare. Regardless of the manner in which these technologies are used, the welfare effects generated by ICTs provide an idea of the benefits associated with their diffusion.

4.2.3 Benefits of ICT – consumer surplus

An alternative method of assessing the effect of these technologies is to examine the welfare effects (consumer surplus) associated with their use. The assumptions underlying this approach are that decision-makers are rational and able to understand their activities better than others, and that the money which they are demonstrably willing to spend on these technologies is at least a minimum measure of the worth of these technologies. Using this rationale, one can calculate the internal rate of return (IRR) and use it as an indicator of the worthiness of a particular investment. However, due to the externalities associated with these technologies and the possibility that consumers may actually benefit more than they pay for a technology, the IRR is often supplemented by estimates of consumer surplus.

While consumer surplus, defined as the gap between the price users are willing to pay and the price they actually pay, is quite a simple concept, there are a number of ways of operationalizing it. Several papers have calculated the consumer surplus associated with ICTs, albeit focusing more on telecommunications than on computers. Here, studies of both types are discussed.

4.2.3.1 Consumer surplus and telecommunications

Saunders *et al*. (1983) provide details of several studies that have estimated the consumer surplus associated with telephone calls. For instance, a study conducted in Costa Rica in 1976 calculates consumer surplus by estimating a part of the demand curve for telephone calls. By observing the response of users to a price increase, the authors compute the price elasticity of demand and the associated decrease in consumer surplus. Adding the reduction in consumer surplus to the original revenues (those in effect prior to the price change) provides an idea of the pre-price-hike benefits associated with telephone calls.[33]

The study in Costa Rica was carried out in somewhat greater detail, using data from 92 public telephones in 82 villages. Based on changes in call traffic following a tariff hike of 25 percent from 12 to 15 centimos per pulse, the average price elasticity in these villages was estimated to be about -0.5. Thus, a village that used 100 pulses per day before the hike would now use 87.5 pulses, with a corresponding decline in consumer surplus of 2.81 colones per day (87.5 x 3 + 1/2 x 12.5 x 3). Adding this loss in consumer surplus to revenue yields a pre-price-hike benefit of 14.81 (12 + 2.81) colones per day, suggesting that measured revenues represent only 81 percent of the benefits received by phone users.

[33] These estimates are based on demand analysis. As the authors point out, in developing countries where demand is seldom met, observations of price and quantity rarely represent points on the demand curve. Nonetheless, since what users actually pay for services reveals at least part of their valuation of the benefits received, the empirical observation of points on the supply curve can yield some insight into consumer surplus.

Similarly, a study conducted in El Salvador in 1977 also shows that including the consumer surplus results in substantially higher benefits than are indicated by estimates that include only telephone revenues.

Another way of estimating the benefits associated with telephones is to examine the costs saved through their use. In this genre of studies, authors usually calculate the alternative costs of communicating as an estimate of consumers' willingness to pay. The gap between the willingness to pay and actual telephone costs is a measure of the consumer surplus associated with telephone use. Several studies of this nature have been carried out on developing countries. These studies are reviewed in detail in Saunders *et al.* (1983). Although these studies suffer from data problems and some questionable assumptions, a common finding across countries is that savings exceed expenditure quite substantially. Depending on the country, region and sample group analyzed, these savings may range from 1.5 to 5.5 times the costs.

4.2.3.2 Consumer surplus and computers

The literature on consumer surplus associated with computers is relatively thin (as compared to that on telephones) and deals mostly with developed countries.

Brynjolfsson (1994) uses data from the US to estimate the increase in consumer surplus associated with the decline in computer prices during the 1975-1987 period. He computes four different measures of consumer surplus, i.e. Marshallian surplus, exact surplus based on compensated demand curves (Hicksian demand curves), a non-parametric estimate and a value based on the theory of index numbers. These will now be described in some detail.

The most common method of estimating consumer surplus is based on the ordinary or the Marshallian demand curve. Given a specification of the demand curve, one can directly evaluate the Marshallian consumer surplus by integrating it between any two prices. Brynjolfsson relies on a log-linear specification of the demand function, i.e.

$$Q = e^{g} p^{a} y^{d} \tag{8}$$

where Q is quantity, p is price, y is income and g, a, and d are parameters to be estimated. Integrating the demand curve from the initial price p_0 to the final price p_1 yields:

$$CS = e^{g} y^{d} \left(p_1^{1+a} - p_0^{1+a}\right)/(1+a) \tag{9}$$

Given prices, income and estimates of the parameters, consumer surplus can be calculated.

However, the Marshallian surplus is not an exact measure of welfare. The appropriate demand curve to use for exact consumer surplus is the compensated demand curve, i.e., a demand curve adjusted so as to maintain the same utility level before and after the price change. In the case of a log-linear demand function, the consumer surplus associated with the compensating variation in income (*CVI*) principle may be calculated as:[34]

$$CVI = \left[y^{1-d} + \frac{(1-d)}{(1+a)} e^{g} \left(p_1^{1+a} - p_0^{1+a} \right) \right]^{\frac{1}{1-d}} . \qquad (10)$$

The additional terms in this expression compensate for the change in real income due to the price decline. These two methods of calculating consumer surplus are based on the estimation of a parametric demand curve. Imposing such a restriction on the shape of the demand curve may not be appropriate and may lead to misleading estimates. An alternative is to compute consumer surplus using non-parametric methods (see Varian, 1993).

The fourth method is based on the idea that consumer welfare is captured by the increase in utility resulting from changes in prices and consumption. Accordingly, instead of relying on a demand function, one may use a utility function to derive a measure of welfare. Based on a translog utility function and some results from the theory of index numbers, Bresnahan (1986) derives such a measure. The measure of consumer welfare associated with such a utility function may be represented as:

$$1/2(S_1 + S_0)\log(p_0 / p_1) \qquad (11)$$

where S_i (i = 1,0) is the share of IT in total expenditure in the final and initial period, respectively.

Brynjolfsson (1994) uses data on 8 US industries for the years 1975 through 1987 to compute these four measures of consumer surplus for computers. The results are remarkably consistent across methodologies and are quite robust to some of the specification tests conducted by the author. Using 1987 as the base year, the estimates suggest that the consumer surplus associated with computers ranges between $50 – $70 billion. When compared with the expenditure on computers ($ 25 billion in 1987), it is clear that the diffusion of computers has generated substantial benefits.

In another study, Bresnahan (1986) uses the index number method to calculate the benefits derived from the spread of mainframe computers in the financial services industry. While pointing out that benefits derived in the financial sector may not generalize to other sectors, the paper reported that in current (1986) terms, the benefits derived from the quality-adjusted price decline in these computers generated benefits on the order of 1.5 to 2 times the expenditure.

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[34] Consumer surplus based on *CVI* may be computed by integrating the demand function to obtain the money metric utility function, which can be used as the basis for calculating exact consumer surplus (see Varian, 1992, for the

Concluding remarks: Notwithstanding the shortcomings of the data and the questionable assumptions underlying some of the studies reviewed here (especially those that use data from developing countries), the message that emerges from these results seems unequivocal. Regardless of the method used to calculate consumer surplus, the welfare effects associated with the spread and use of these technologies are substantial. On the basis of these welfare effects (returns on investment), additional investments in these technologies seem justified.

4.3 The effect of ICTs on individual earnings and earnings distribution

As argued in section 3, it is possible that the diffusion of ICTs may exacerbate existing wage inequalities in developing countries by enhancing the demand for skilled labor. The manner in which these technologies influence labor-market outcomes, i.e. wages and employment, has been examined by several authors, but all of their studies are based on data for developed countries. Nevertheless, results from developed countries may provide a preview of the outcomes to be expected in developing countries. This section proceeds by reviewing first the evidence regarding these technologies' effects on wages and then their effects on employment.

4.3.1 ICTs and wages

One of the first papers to examine the impact of computer use and wages is Krueger (1993). Krueger uses data extracts from the United States Current Population Surveys conducted in 1984 and 1989 to explore whether workers who use a computer at work earn a higher wage than otherwise similar workers who do not use a computer at work. Additionally, the paper examines the extent to which the computer-usage wage premium may be responsible for the recent changes in the US wage structure (i.e. greater wage inequality; see Juhn, Murphy and Pierce, 1993). The methodological approach utilized by Krueger consists of augmenting a standard cross-sectional earnings function with a dummy variable indicating whether an individual uses a computer at work.[35] That is a log linear specification:

$$\ln W_i = X_i b + C_i a + e_i, \tag{12}$$

where individual *i*'s wage rate W_i depends on a vector of observed characteristics X_i,[36] an indicator variable C_i representing the use of a computer at work and an error term e_i. This regression is estimated using both data waves (i.e., data from 1984 and from 1989).

money metric utility functions associated with other standard demand functions). Note that the Marshallian surplus estimates are often not a bad approximation of exact consumer surplus (Willig, 1976).

[35] Using a computer refers only to the respondent's direct or hands-on use of a computer with a typewriter-like keyboard. The computer may be a personal computer, minicomputer or a mainframe computer.

[36] The *X* vector includes a conventionally selected set of regressors. Specifically, years of education, experience, occupational dummies, regional dummies, and indicator variables for marriage, gender and race.

For both years, the estimates show a positive and statistically significant effect of computer use on wages. The point estimates indicate that there was a substantial computer premium of around 18.5 percent in 1984, which increased to 20.6 percent in 1989. To provide an idea of the type of computer use which is most productive, Krueger examines the impact of specific, computer-related tasks on wage premiums. That is, the wage specification (12) is augmented with 11 task-specific indicator variables.[37] The coefficients for the specific tasks should be interpreted as indicating the additional payoff associated with the specific task relative to any computer use at all. The highest payoffs seem to be associated with the use of e-mail, which probably reflects the concentration of high-ranking executives who use e-mail. Interestingly, the payoff for playing computer games is negative, suggesting that the use of computers for nonproductive purposes does not enhance earnings.

Although the computer-use wage premium is large and statistically significant, a critical concern is whether these estimates really reflect the effect of computer use on wages or are a spurious correlation reflecting the unobserved quality of workers who use computers. Recognizing this problem, Krueger tries out several empirical strategies to discern whether his results are sensitive to sample-selection bias. The results stand up to scrutiny and, regardless of the empirical strategy used, a 10-15 percent computer-use wage premium remains, suggesting that workers who use computers earn more as result of their computer skills.

Having established that the use of a computer at work is accompanied by an increase in mean wages, an issue which naturally flows from these results is whether the impact of using a computer is uniform across skill groups. To examine this, a specification that includes both a computer dummy and an interaction between the computer dummy and years of education is estimated:

$$\ln W_i = X_i b + E_i r + C_i a + C_i . E_i g + e_i , \qquad (13)$$

where E is years of education. Results from both the data waves show a positive coefficient on the computer dummy-education interaction term, indicating that the computer premium is higher for more highly educated workers. The inclusion of the computer dummy and interaction term also decreases the increase in the rate of return on education, i.e., the coefficient of E. This indicates that a portion of the increase in educational returns may be attributed to computer use. After conducting several sensitivity checks to assess the robustness of the results, Krueger concludes that the proliferation of computers accounts for between one-third and one-half of the increase in the rate of return on education between 1984 and 1989.

[37] These specific tasks include word processing, bookkeeping, computer-aided design (CAD), e-mail, inventory control, programming, desktop publishing, spreadsheets, sales and computer games.

In his work, Krueger appears to conclude that there is a causal link between computer usage and the wage premium. Whether this is true or whether the computer-use wage premium is a result of unobserved worker heterogeneity, i.e., workers with attributes that lead to higher wages are more likely to use computers on the job, is currently a subject of dispute. To examine this issue in greater detail, Di Nardo and Pischke (1997) use data from West Germany (three cross-sections of the Qualification and Career Surveys conducted in 1979, 1985-86 and in 1991-92) to examine the same question as Krueger.

Despite the institutional differences between the US and the German labor markets, patterns of computer use and the computer-use wage premium are similar in the two countries. The computer-use wage premium shows a steady increase from 11.8 percent in 1979 to 16.9 percent in 1985-86 and 18.6 percent in 1991-92. In an attempt to shed light on the causal link between computers and wages, the authors now examine the wage returns on other office tools. Surprisingly, they report that the returns on pencil use are of the same magnitude as that for computers. It is difficult to believe that the use of pencils renders individuals more productive. A more appropriate interpretation is that the positive returns on pencil use reflect selection effects. The authors argue that if this type of selection is important for pencils, it may be equally important for the computer effect. Accordingly, the authors conclude that the computer-use wage premium is largely the result of unobserved worker heterogeneity.

Using cross-sectional data for the years 1987, 1989, 1991 and 1993 and a similar framework, Asplund (1997) examines the impact of computer use on wages in Finland. The results reveal that over the years, there is a steady erosion of the computer-use wage premium. The premium declines from 8.76% in 1987 to a negligible effect in 1993. Dividing the computer-use variable into six categories based on the type of computer used also reveals a similar pattern. One reason for this particular pattern may lie in the spread of computer use. Compared to other developed countries, Finland has more widespread computer use. If the selection story is true, then as computer use spreads and less skilled workers gain access to computers, the computer-use wage premium should decline. While this story may be true in the Finnish case, it is at odds with the results in Germany and the US, where the wage premiums have increased in spite of the diffusion of computers.

Further evidence based on more comprehensive cross-sectional and panel data from France (French Labor Force Surveys conducted in 1985 and 1987) is provided by Entorf and Kramarz (1997, 1998). Their data allows them to construct three computer indicator variables and three “experience with computer-use variables”. The three computer-use categories are constructed on the basis of the type of ICT involved (i.e., whether the technology is an office or a manufacturing technology) and the amount of autonomy left to the user. These categories correspond roughly to the educational/skill levels of the workers. The first two categories are computer-based NT (new technology) involving high and average degrees of autonomy, respectively, and the third is production-based NT involving a low degree of autonomy. Based on a regression similar to those described above, the authors find that significant wage premiums exist only for the first category of computer users (17.1 percent). The addition of the experience variables suggests that a large proportion of this premium is due to experience with new technologies (10 percent). The high returns to the first category of computer users suggest that the results may be driven by selection bias. To examine this possibility, the authors now exploit the panel nature of their data.

Results based on panel-data regressions differ sharply from the cross-sectional results. The coefficients on the computer-use variable for all three categories are small and statistically insignificant. Turning to the experience variables, at least for the first category of computer users, there seems to be positive returns on computer experience. This return is approximately one percent for each year of experience. However, due to the rapid obsolescence of knowledge, these returns peak quite rapidly (around 6 years) and remain flat thereafter. Overall, the results suggest that computer users are selected on the basis of skill levels and that a substantial portion of the computer-use wage premium reflects returns on unobserved heterogeneity. However, experience with these technologies also increases the productivity of these skilled workers and leads to further wage increases. The authors note that this pattern of results is quite consistent with the slow increase in wage inequality observed in France in recent years.

Evidence based on panel data, albeit restricted to the manufacturing sector, is also provided by Doms, Dunne and Troske (1997). The authors combine individual and plant data from a variety of sources to create a panel data set that matches 34,034 workers to 358 manufacturing plants. One of the aims of their paper is to examine how plant-level wages vary with the adoption and use of factory automation technologies. In contrast to other papers (Berman, Bound and Griliches, 1994; Autor, Katz and Krueger, 1997) that use measures of technology that are primarily information-processing technologies, Doms *et al.* (1997) construct technology measures reflecting the use of ICTs in manufacturing. Plants are classified as high- or low-technology plants on the basis of the number of technologies they use. To examine the effect of technology while controlling for other variables, the authors regress average plant wages for three categories of workers on their respective measures of technology. Based on a cross-sectional regression, the authors find that there is a wage premium for workers in high-technology plants. Average wages in high-tech plants are between 8.7 and 13.5 percent higher for production and technical workers.

To examine the robustness of these results, the authors now use the longitudinal element of their data to examine whether increases in average plant wages between 1977 and 1992 are correlated with the number of advanced technologies adopted between 1977 and 1993. Their results show that there is little correlation between the adoption of such technologies and plant-level changes in workers' wages. Despite a number of other sensitivity checks, their basic message remains unchanged, i.e., technology adoption is not correlated with workers' wages. Further investigations reveal that the most technologically advanced firms paid their workers higher wages prior to the adoption of these technologies and had high-productivity plants, both prior to and after adoption. This again suggests that the cross-sectional correlation between wages and computer use reflects unobserved worker-quality differences. Overall, the results are consistent with the conclusion that firms with more highly skilled workers are more likely to adopt new technologies. However, subsequent to adoption, these technologies do not have much of an impact on wages.

Thus far, the focus has been on the question of how computer use influences wages. While it is possible to use these estimates as a basis for drawing conclusions regarding wage inequality, a more direct approach may hold greater appeal. For instance, Autor, Katz and Krueger (1997) use US data covering 140 three-digit industries over the 1940-1995 period to establish first that the increase in the relative demand for skilled workers is driven primarily by skill-upgrading within industries, rather than by a "between-industry" shift in demand[38]. Following that, they examine whether the within-industry increase in demand for skilled labor is related to industry computer use. Specifically, they study whether the annualized change in the college-educated workers' wage bill in each industry (an indicator of within-industry skill upgrading) is related to the changes in the fraction of workers in the industry who use a computer.[39] They examine this relationship by dividing their sample into four periods (1960-70, 1970-80, 1980-90 and 1990-95). Their results indicate that between 1970 and 1995, there is a strong relationship between the shift towards college-educated workers and computer adoption. The results suggest that a substantial portion (around 50 percent) of the increase in the share of the wage bill devoted to college-educated workers may be explained by the change in computer use.

To examine whether their results are specific to computers or reflect broader patterns of capital-skill complementarity, the authors combine their information on wage bills and computer use with industry data on capital stocks. The estimates indicate that there is a strong positive relationship between an industry's computer capital at the start of each decade and the growth in the share of that industry's wage bill paid to college-educated employees. The impact of computer capital is not substantially influenced when the change in the capital-labor ratio is added to the regression. The finding that the initial stock of computer capital has an impact on relative wages hints at a mechanism by which an increase in computer investments calls forth an increase in the demand for skilled labor.

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[38] A between-industry increase in demand would imply that demand has shifted to those industries which employ more highly skilled labor.

[39] Note that the increase in the share of college-educated workers in the total wage bill depends on the increase in wages, as well as on the increase in the employment of college-educated workers. Thus, this variable reflects the effects of ICTs on wages and employment.

Berman, Bound and Griliches (1994) use data from US manufacturing industries to examine the sources of increased demand for skilled workers. Similar to Autor *et al.* (1997), they report that most of the increases in demand for skilled labor stem from within-industry effects. Further, they investigate whether the increase in demand for skilled labor is due to computer use. Based on their indicator of skill upgrading (i.e. the annual change in the non-production workers' share of the wage bill), they report that between 25-50 percent of the increase in demand for skilled labor may be explained by the diffusion of computers. Regardless of the causal link, the authors note that within-industry skill upgrading has occurred primarily in those industries that have invested most heavily in computers. A similar conclusion is echoed in Autor *et al.* (1997), who note that increases in the demand for skilled labor are concentrated in the most computer-intensive sectors of the US economy.

The papers by Autor *et al.* (1997) and Berman *et al.* (1994) suggest that increases in US wage inequality are driven largely by the increase in relative demand generated by the diffusion of computers. Since the diffusion of computers is fairly widespread in the developed world, it would be instructive to examine whether similar patterns of changes in relative wages prevail in other developed countries. To examine this pattern, Card, Kramarz and Lemieux (1997) use labor survey data from the beginning and the end of the 1980s from the US, Canada and France to examine the impact of the diffusion of computers on wage growth. Specifically, they construct narrowly defined age-education cells and examine the effect of computer use rates (the share of computer users in each group) on the wage growth of these age-education cells. Their results show that in the case of the US, the effect of computer use on wage growth is as expected. For both males and females, wage growth is positively correlated with computer use. The Canadian data indicate no strong relationship. The results for France are quite surprising as they suggest that average wage changes for both men and women are negatively linked to computer use, i.e. workers who use computer technology more intensively report lower growth in wages than workers who do not use these technologies.

4.3.2 ICTs and employment

Thus far, the discussion has focused largely on the effect of ICTs on wages or relative wages. This section takes a closer look at how these technologies affect the composition of employment.

Doms *et al.* (1997) examine the plant-level correlation between advanced technology use and the share of non-production workers in total employment. Consistent with the notion that skilled workers and advanced manufacturing technologies are complements, the authors find a positive correlation between the two variables. However, they find no positive relationship between the change in the share of non-production workers between 1977 and 1992 and the increase in technology use. While their study relies on data from a small set of plants and examines the effect of manufacturing-related ICTs, the differences between these results and those presented by Berman *et al.* (1994) and Autor *et al.* (1997) are striking. In an attempt to reconcile these differences, the authors construct a computer-investment variable (similar to those used by other authors) and examine the effect of this variable on the share of non-production workers. Regressions using these variables suggest that the share of non-production labor is positively and significantly correlated with computer investments.

Evidence relating to changes in the skill composition of the work force from other developed countries is reviewed in Kramarz (1998). A study of 402 plants in Britain suggests that the introduction of computers in plants is associated with an increase in the share of white-collar workers at the expense of unskilled, manual workers. Similar results are found in a study using data from French firms.

Despite the cross-country consistency of these studies (based on firm-level data), the results regarding the influence of computer use on employment obtained from workforce data does not display the same pattern of consistency. Card *et al.* (1997) examine the effect of computer use on the employment rates of various age-education groups. Based on their knowledge of the institutional environment in these three countries, the authors expect that the effect of these technologies would have the greatest negative impact on employment in France, followed by Canada and then the US (alternatively, computer use should be most strongly related to the employment rates of skilled workers in France, followed by Canada and the US).[40] However, the results do not seem to follow this pattern. In the case of the US, the results show that groups that use computers most intensively record an increase in group employment rates. In the case of Canada and the female sample in France, there is no significant computer use-employment relationship. The results from the male French sample are similar to those obtained for the US. This indicates that despite the wage rigidity in France, the magnitude of the relative decline in the employment rates of less skilled workers (which may be explained by the diffusion of computers) is the same as that in the US.

Concluding remarks: The evidence reviewed above suggests that, at least in the case of the US, the increase in the relative demand for skilled labor and the subsequent increase in wage inequality are related to the spread of ICTs. However, results from other developed countries that have had a similar diffusion in computer use do not provide such a clear picture. This suggests that the outcome in each country/region varies according to the different institutional features governing the labor market (training possibilities, unions, minimum wages and collective bargaining). While it is possible that ICTs may enhance the demand for skilled labor, impeding their diffusion on the basis of distributional concerns seems unwarranted.

[40] This hypothesis is based on the idea that, if a similar negative demand shock affects less skilled workers in all three countries, then given the labor market flexibility in the United States, the shock should result primarily in a decline in the relative wages of less skilled workers. In France, where labor markets are relatively inflexible, the shock should result largely in a decline in the relative employment of less skilled workers.

5 Conclusion and Research Implications

The spread of ICTs has been heralded as a new tool to help low-income countries achieve faster growth and development. Too often, however, a highly unlikely array of benefits is ascribed to their use. To understand why these technologies have generated so much enthusiasm, this paper examined three issues: first, what are the unique characteristics of these technologies; second, what are the links through which these technologies are expected to promote development, and third, how well does the existing empirical evidence support the claims made for or against the spread of ICTs.

Characteristics unique to ICTs included their capability to promote the separation of information from its physical repository, their pervasive, economy-wide effects and the externalities (content and network) generated by their use. The manner in which ICTs might promote development was examined by considering their effects on the functioning of organizations, on the enhancement of market efficiency and access and on the promotion of institutional change. Their potential distributional consequences were examined, and the empirical evidence available in each of these areas was surveyed.

The empirical evidence from cross-country studies suggested that a minimum threshold of ICT density was required in order for these technologies to exert an influence on growth. The evidence from firm-level studies indicated that there might be substantial time lags between ICT investments and their positive effects. These lags also suggest that re-training of workers and workplace re-organization may be required in order for these technologies to fulfill their potential. Studies that have calculated the consumer surplus associated with ICTs have usually found substantial welfare effects associated with their use. A survey of the effects of ICTs on wages and employment suggested that, at least at the moment, concerns about potential negative distributional consequences of ICTs seem unwarranted. Overall, the impression that emerges from the empirical work is that there may be substantial benefits associated with the spread of ICTs.

However, it should be noted that a preponderance of the empirical literature surveyed here is based on data from developed countries. To build a credible body of evidence on developing countries, the foremost task is to improve the quality and availability of data. With appropriate data and suitable empirical tools as suggested by this review, careful empirical work in a variety of areas may be fruitful.

First, there are relatively few studies that examine how ICTs affect the productivity of firms in developing countries. In addition to productivity, a more comprehensive analysis of the manner in which these technologies affect other outcomes such as product development and product quality is required. A clear demonstration of the benefits associated with the use of ICTs may provide firms with the motivation required to invest in these technologies.

Second, the argument that the use of these technologies reduces transaction costs and thus promotes the spread of markets is largely unverified. While anecdotal evidence is available, there is limited empirical work that links the diffusion of these technologies to the increased efficiency and spread of markets. Similarly, the issue of whether the diffusion of these technologies promotes institutional change is still unclear.

Third, it is often asserted that the use of these technologies and the benefits they confer are limited to a minority of households. Thus, their spread may exacerbate informational and income inequalities. While a number of studies have examined the effects of ICTs on household welfare, there is only relatively weak evidence regarding the issue of whether and, if so, in what way household welfare varies according to income or poverty levels. Further work should focus on who uses these technologies and how the benefits generated by their use are distributed. In order to ascertain whether it is true that the diffusion of these technologies exacerbates income inequality, it will be necessary to conduct detailed studies of these technologies' effects on the internal organization of firms, hiring patterns and the skill-mix of employees. Additionally, labor market surveys may be used to analyze the effects of ICTs on individual wages and employment patterns. Studies that address these distributional concerns and the impact of these technologies on the poor are needed to inform the debate over the worthiness of additional investments in information and communication technologies.

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