DIFFUSION OF INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT) AND INCOME INEQUALITY: A SURVEY

Dissertation submitted to Jawaharlal Nehru University in partial fulfillment of the requirements for the award of the degree of

MASTER OF PHILOSOPHY

SAMBIT RATH

CENTRE FOR STUDIES IN SCIENCE POLICY
SCHOOL OF SOCIAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110067
2004

जवाहरलाल नेहरू विश्वविद्यालय
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110067

Centre for Studies in Science Policy
School of Social Sciences

Date: 28.07.04

CERTIFICATE

This is to certify that the Dissertation entitled **"Diffusion of Information and Communication Technologies (ICT) and Income Inequality: A Survey"** submitted by **Sambit Rath** for the award of the degree of **Master of Philosophy (M.Phil.)** of the Jawaharlal Nehru University is his original work, carried out under my supervision and guidance.

It is hereby certified that his work has not been presented for the award of any other degree or diploma to any other University in India or abroad. This Dissertation being presented is worthy of consideration for the award of M.Phil. degree of the Jawaharlal Nehru University.

for V.V.K.

Prof. Nasir Tyabji
SUPERVISOR

Prof. V.V. Krishna
SUPERVISOR

Prof. P.N. Desai
CHAIRPERSON

Dedicated to

Godot

……we are still waiting for you

ACKNOWLEDGEMENT

I have received help from many people at every stage of this work this work--both intellectually and materially --and this space is far too short to acknowledge them all.

I am extremely grateful to my esteemed supervisor Prof. Nasir Tyabji whose scholastic co-operation helped me in conceptualising and accomplishing this academic work. I express my deep gratitude to my supervisor Prof. V.V. Krishna and our Chairperson Prof P.N. Desai for their support throughout my M.Phil work.

I would like to specially thank Manoranjan, Vincent and Swapna Sarit in who have been a great help all through. And Daron, where would I have been without you!

Finally, this work of mine owes a lot to JNU.

SAMBIT RATH

Contents.

Page No.

CHAPTER- I

INTRODUCTION

The history of capitalism from the industrial revolution onwards is one of increasing differences in productivity and living conditions across different parts of the globe. According to one source, 250 years ago the difference in income or productivity per head between the richest and poorest country in the world was approximately 5:1, today this difference has increased to 400:1.[1]

The prevailing view in economics nowadays is that technology—rather than the accumulation of physical and human capital— accounts for most of the income and growth differences across countries[2]. Economic growth is driven by advances in technology, that is, in ideas about how to produce more efficiently. Consequently, a country is poor because it does not have access to the ideas that are used in industrial nations to generate economic value. The fact is that the G-7[3] countries account for about 90 per cent of the world's spending in research and development activities aimed at creating new innovations. They also produce 90 per cent of all the patents granted in the United States.

It is only recently that economists have looked into the effects of these inequalities (particularly income inequalities) over the growth pattern of different countries. The emergence of every new technology creates new relations of production. The old order gives way to the new, but the institutions built around the old mode of production persist. The extant income inequalities make the diffusion pattern of these technologies very much skewed. This in turn

---

[1] See Landes (1998), p-13.

[2] See, e.g., Easterly (2001), Easterly and Levine (2001)

[3] G-7 industrial economies—the United States, Canada, Japan, France, Germany, Italy, and the United Kingdom.

makes it even more difficult for the already disadvantaged ones to pick up the innovations. This may not always be the case, since the skill-bias of each technology always does not depend upon the tacit skill base. The technology frontiers do shift in favour of the nations at the backwaters of underdevelopment. But, the new information and communication technologies show a very disturbing trend. Being networked technologies, they had promised faster diffusion. However, new patterns of inequalities are emerging.

1.1 Relationship between GPT[4] and Growth: An Evolutionary Perspective

Economic growth is driven by many factors: economic, political, and cultural. While economists have traditionally emphasised the role of accumulation of conventional inputs (e.g. labour, and capital) as the primary force behind output expansion, more recently greater attention has been paid to political and technological factors[5]. Economic historians have placed great weight on technology as a force of change.[6] Macroeconomists, on the other hand, used to downplay its role, mostly due to the inability to analyse forces that shape technological change. In recent years, however, this attitude has changed. Following Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), many macroeconomic studies now place technological progress at the centre of the growth process. This change has been triggered by theoretical developments that allow micro-economic aspects of innovation[7] to be linked with macroeconomic outcomes.

---

[4] GPT stands for "General Purpose Technology", to be defined later on in this section.

[5] See for example, Aghion and Howitt (1992), Helpman (1998)

[6] See, e.g., Landes (1969), Rosenberg (1982), and Mokyr (1990)

[7] Innovation needs to be distinguished from invention (discovery): "As long as they are not carried out into practice, inventions are economically irrelevant. And to carry any improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes. Although entrepreneurs *may* of course be inventors just as they may be capitalists, they are inventors not by nature of their function but by coincidence and vice versa." (Schumpeter 1934, p. 89)

1.1.1 Schumpeterian Perspective of Growth

The basic premise, which characterises Schumpeterian approach, is that, growth is driven by innovation and its gradual diffusion. For more almost fifty years, from the beginning of the 1900s until his death in 1950, Schumpeter was the leading academic protagonist for an "evolutionary"[8] approach to long-run economic development. Schumpeter's approach may be seen as an interesting amalgam of the main approaches that he encountered as a student in Vienna around the turn of the century, namely Marxism, the (German) historical school in economics and the (emerging) neoclassical strand. From Marx he took the dynamic outlook, from the historical school the emphasis on historical specificity (with respect to technology, industry/sector, institutions and so on) and from the neoclassicals the need for a micro-based approach, in which evolution is explained through the interaction of individual actors, rather than through some metaphysical force that works its way through history. With evolution Schumpeter meant qualitative, economic change brought about through innovation. Or, in his own words: "*The changes in the economic process brought about by innovation, together with all their effects, and the response to them by the economic system, we shall designate by the term Economic Evolution*"[9]. In this attempt Schumpeter was heavily influenced by the dynamic vision that he found in Marx' works.[10]

---

[8] Broadly speaking, emphasis on- a) innovation as the driving force behind economic, social and institutional change, b) the central role played by capitalist firms in this process and c) a historical perspective, characterize the approach.

[9] Schumpeter 1939, vol. I, p.86

[10] For a comparative discussion of the works by Marx and Schumpeter see Eliott (1984).

According to the evolutionary economists, there is a consensus that growth is driven by innovations or technological progress.[11] The incremental nature of technological progress has been well documented by economic historians.[12] But so were major path-breaking inventions that had far-reaching and prolonged implications, such as the steam engine, electricity, and the computer.[13] This has parallels with the Kuhnian[14] conception of the history of science. Incremental innovations, along with imitation activities (diffusion), sustain economic growth; but, the spurt in the growth patterns is almost always associated with a drastic innovation of far reaching proportions.

1.2 General Purpose Technologies (GPTs)

We shall qualify these drastic innovations alluded to earlier in the previous section, as *general purpose technologies* (GPTs). An innovation is known as a GPT if it has the potential for pervasive use in a wide range of sectors in ways that drastically change their modes of operation. To quote from Bresnahan and Trajtenberg (1995), who coined the term GPT and provided a highly original discussion of its usefulness,

"Most GPTs play the role of "enabling technologies", opening up new opportunities rather than offering complete, final solutions. For example, the productivity gains associated with the introductions in manufacturing were not limited to a reduction in

---

[11] This preoccupation with technology (the so called neo-technological approach) is actually the revival of a old tradition rather than a new one. For, even during the years when macroeconomists shied away from technological progress there were other economists, such as Christopher Freeman, Zvi Grilliches, Edwin Mansfield and Nathan Rosenberg, who studied the economic aspects of technology. (Helpman, E. (1998), p. 2)

[12] See Rosenberg (1982).

[13] See von Tunzelmann (1978) on steam engine, Du Boff (1967) on electricity, and David (1991) on the parallels between electricity and the computer.

[14] Kuhn (1962), in *The Structure of Scientific Revolutions* spoke about the paradigm shifts, in a similar fashion.

energy costs. The new energy sources fostered the more efficient design of factories, taking advantage of the new found flexibility of electric power. Similarly, the users of micro-electronics benefit from the surging power of silicon by wrapping around the integrated circuits their own technical advances. This phenomenon involves what we call "innovational complementarities" (IC), that is, the productivity of R&D in a downstream sector increases as a consequence of innovation in the GPT technology. These complementarities magnify the effects of innovation in the GPT and help propagate them throughout the economy."(p. 84)

This description makes clear two important features of drastic technological innovations that qualify as GPTs[15]: generality of purpose and innovational complementarities. Some examples of the GPTs are: writing (first appeared in Sumerian Civilization), printing; use of the first metal- bronze; power delivery systems like, waterwheel, steam, electricity, internal combustion engine; and the recent information and communication technologies (ICTs) etc.

1.2 Emergence of ICTs: the New GPT

In the latter part of the twentieth century, information and communication technologies (ICTs) came to be used everywhere—in offices, factories, and homes—and transformed the way things are done in activities as diverse as jet aircraft design, document production, and home entertainment. These technologies have also improved tremendously, as evidenced, for instance, by the quick succession of more powerful computers with faster processors, greater storage capacity, and so forth. The use of computers in diverse applications is similar to the use of earlier technologies, such as steam and electricity, and

[15] There have been many similar approaches propounded by several other authors, namely, "technoeconomic paradigm" (TEP), a somewhat broader concept than GPT, by Freeman, Clark, and Soete (1982); "macro inventions" of Mokyr (1990); "enabling technologies" of Lipsey and Beker (1995), etc.

looking at the evolution of those older technologies is necessary to understand both how computers diffused through the economy and the effects they were likely to have on it.

Innis (1951, 1972) was the first economist to treat information and communication technologies (ICTs) as the fundamental technology from which all major technological achievements of our time flow.[16] His ICTs have three basic characteristics: to store, to transmit, and to reproduce information.

The latest ICT revolution is being driven by the electronic computer in many and varied forms.[17] To speak briefly, ICTs encompass, computers and automatic data processing machines, including, micro-electronics and associated equipment; all collection, storage, retrieval, and dissemination media and modes such as CD-ROM, optical discs etc.; telecommunication devices, network linkages (local and wide-band); software (standard and customized); and internet. Thus, as Helpman et al. (1998) have said ICTs qualify to be GPTs by any defination.

1.3 Aspects of Diffusion of GPTs and Inequality

Diffusion of innovations can be said to be the most important factor to account for the differential growth patterns seen across the world. Taking a Schumpeterian perspective, we can assume that technological innovations are the sustaining force of economic growth. The diffusion of any GPT creates newer kinds of inequalities in the society. There are many reasons for this phenomenon: diffusion of innovation itself creates divisions in the society among the people at various stages of adoption; monopoly rents[18] equip the pioneers better to adopt

[16] He did not use the term GPT explicitly. Dudley (1995) followed his framework.
[17] For a survey of ICTs, see Greenwood (1997).
[18] Monopoly rent is the windfall accruing to the pioneer who virtually reaps the monopoly benefits out of the adoption of the innovation.

the newer technologies coming in the same GPT; skill-bias associated with any GPT tends to exacerbate the pressure on the human capital, which in turn distorts the wage inequality scenario etc.

1.3.1. Diffusion of Innovations

Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. Diffusion is a special type of communication concerned with the spread of messages that are perceived as new ideas. The four main elements in the diffusion of new ideas are (1) the innovation, (2) communication channels, (3) time, and (4) the social system.[19]

The stages through which a technological innovation passes are:

- **knowledge** (exposure to its existence, and understanding of its functions);
- **persuasion** (the forming of a favourable attitude to it);
- **decision** (commitment to its adoption);
- **implementation** (putting it to use); and
- **confirmation** (reinforcement based on positive outcomes from it).

Early knowers generally are more highly educated, have higher social status, are more open to both mass media and interpersonal channels of communication, and have more contact with change agents. Mass media channels are relatively more important at the knowledge stage, whereas interpersonal channels are relatively more important at the persuasion stage.

---

[19] Rogers E.M. (1983), pp.13

Important characteristics of an innovation include:

- relative advantage (the degree to which it is perceived to be better than what it supersedes);
- compatibility (consistency with existing values, past experiences and needs);
- complexity (difficulty of understanding and use);
- trialability (the degree to which it can be experimented with on a limited basis);
- observability (the visibility of its results).

Different adopter categories are identified as:

- innovators (venturesome);
- early adopters (respectable);
- early majority (deliberate);
- late majority (sceptical);
- laggards (traditional).

Earlier adopting individuals tend not to be different in age, but to have more years of education, higher social status and upward social mobility, be in larger organisations, have greater empathy, less dogmatism, a greater ability to deal with abstractions, greater rationality, greater intelligence, a greater ability to cope with uncertainty and risk, higher aspirations, more contact with other people, greater exposure to both mass media and interpersonal communications channels and engage in more active information seeking.

1.3.2. Skill Bias and GPTs

Since, GPTs are the overwhelming technological paradigm of every epoch, and the fact that they almost always require specialised skills for an adopter to use it, they create a division between the skilled and the unskilled.

In this connection, over the past two decades the economic literature[20] has offered an explanation of this empirical evidence based on the so-called "Skill Biased Technological Change" (SBTC) hypothesis, according to which the reason for the upskilling of the labour force is the non-neutrality of technological change, which benefits skilled labour more than other production factors. Because technology is complementary to skills, acceleration in the rate of technological change increases the demand for skilled labour; yet it is also true that an increase in the supply of skills induces faster technológical change.[21]

One explanation put forward by economists to reconcile these facts hinges on the nature of technological change over the past two decades. Indeed, whilst the phenomenon of SBTC appears to be a long-term historical trend[22], the diffusion of Information and Communication Technology (ICT) seems to have given new impetus to the substitution of unskilled workers with skilled ones. As technologies like ICT proved successful in raising the marginal productivity of skilled labour relative to unskilled labour, they also made it relatively more economical to employ skilled workers in place of unskilled ones. Accordingly, Michel and Bernstein (1966) and Wood (1995) argue that the 1980s witnessed acceleration in SBTC which resulted in rising skill premia[23] in many countries[24].

---

[20] See section 1.4 in this chapter.
[21] See, among others, Greiner *et al.*, (2001)
[22] See Nelson and Winter, 1982; Dosi, 1988; Goldin and Katz, 1998, Von Tunzelmann and Anderson, (1998).
[23] Defined as the ratio between the wages earned by high-skilled workers and the wages earned by low-skilled workers.
[24] See also Aghion and Howitt, (2002).

However, since the evidence for this acceleration is mixed[25], one might contend that, within a multi-sector framework, it is mostly the sector bias of technological change that is in operation, rather than the factor bias usually mentioned by labour economists. This explanation is consistent with empirical evidence supporting the SBTC hypothesis for high-tech countries (such as the US and the UK) but not for medium or low-tech ones.

Given that the lit change favours a certain factor o ı sectors than in others[26], some re ıry explanations of the skill bias. re connected to globalisation[27], whereas among industrial and managerial economists they concern the reorganisation of production.

1.5 Survey of Literature

The recent increase in economic inequality in most developed countries has been attributed to the diffusion of information technology, especially computers, raising the wage premium for computer programmers and, in general, computer literate people (see, for example, Acemoglu 2002a).

---

[25] See Autor *et al.*, (1998).

[26] See Haskel and Slaughter, (2002)

[27] This strand of literature supports the hypothesis that increased volumes of world trade and FDI cause a reallocation of the labour force, shifting activities involving unskilled workers towards the least developed countries, while activities involving the production of skill-intensive goods remain in developed countries (Wood, 1994; for an empirical test on Italian data see Manasse *et al.*, 2003). Owing to a lack of data, testing this hypothesis empirically is often a difficult undertaking; however, some studies on the subject have not found a strong support for this explanation of the skill bias (see Slaughter; 2000; Piva and Vivarelli, 2002 and 2004).

The skill-biased technological-change hypothesis is based on the assumption that there is a complementarity between skills and new technologies. Several models have provided a formal way to interpret this hypothesis, including Krussell et al (1997), Vindigni (2002), Acemoglu and Pieshcke (2000) and Card and Lemieux (2000), Bound & Johnson (1992), Schmitt (1999). Caselli's (1999) approach is more flexible and sophisticated, since instead of focusing on the substitutability between skilled and unskilled labour or skill-complementary technology, he focused on *substitutability among technologies,* where technological change is produced by substitution between types of capital. Technological change can be skill biased (if new skills are more expensive to acquire than the skills required by pre-existing technologies, i.e. information technologies) or de-skilling (if the new skills can be acquired at a lower cost than the pre-existing technologies, i.e. assembly line). Aghion and Williamson (1998), while acknowledging that the drivers of inequality are little understood, still argue that one of the factors that pushed income inequality up has been technological change.

Other researchers have focused on other explanations for the increase in inequality. Acemoglu (2002b) compares changes in the wage structure in the United States, the United Kingdom and Continental Europe. While he agrees with the fact that wage inequality rose because the demand for high skilled workers increased relative to their supply, he raises the question of why the process has been different in Europe. He gives three explanations. One is that relative supply of skills increased faster in Europe accounting for less increased in inequality. Second, the European wage institutions (such as unions) have helped to prevent rising inequalities. The third explanation, non-traditional, suggests that technical change has been less skill biased in Europe, maybe due to different explanatory factors: countries develop their own technologies which are less skill-biased or that those countries may lag behind the world technology frontier having different incentives to adopt new technologies. In this sense, and due to wage compression in Europe, firms may find it more profitable to adopt new technologies that fit more unskilled workers. Consequently, job creation is less profitable in Europe and in the long run, it manifests in the increase of unemployment.

In terms of empirical work, Krueger (1993) found evidence that employees that directly use computers at work earn higher salaries. Because highly educated workers are more likely to use computers on the job, the proliferation of computers (technological change) explains, according to this author, the increasing returns to education between 1984 and 1989. Autor et al (1991) follow along similar lines, and find that the diffusion of computers explains 40% of the changes in wages toward college graduates, while investments in computers accounts for at least 30% in the increase in the rate of within-industry skill upgrading. Challenging these findings, DiNardo and Pischke (1997) believe that the causal effects of computer use on wages are not so straightforward. Applying similar statistical techniques to those used by Krueger, they illustrate that the wage differentials associated with the use of calculators, a telephone, a pen or a pencil, or even sitting on the job, are very similar to those measured by computer use. Instead, their results suggest that computer users have unobserved skills which may have little to do with the use of computers but that are rewarded in labour markets, or that computers were introduced in jobs that were already of higher wages.

Borghans and ter Weel (2002) take a different approach. They start from the observation that computer use increases individual productivity as well as the supply of goods. They argue that the maximum level of wage inequality depends on the distribution of productivity of workers within and between groups. In the initial phase, wage inequality tends to increase. In the long run, wage inequality tends to decrease depending on the productivity gains from using computers.

These authors also explore a related issue. They wonder if computer skills are really needed to use a computer. They conclude that computer skills in general do not yield significant labour market returns, unless we refer to the highest level of sophistication in the use of computers, which is not widespread.

Acemoglu and Zilibotti (2001) are concerned with differences in productivity between the developed and developing countries. The differences arise because most technologies adopted by developing countries are developed in the industrialized countries and thus are designed to make optimal use of the skilled labour force. In less developed countries, the workforce is less skilled, and so less productive. The obvious consequence is that even if all countries have equal access to new technologies, the mismatch between skills and technologies leads to differences in total factor productivity. Other problems associated with less developed countries are the following: the specialization of the South in low skilled tasks, and the lack of poor intellectual property rights enforcement. In response to these issues they suggest that protecting property rights and educating the labour force would lead to convergence and income and productivity inequalities would stabilize.

The literature on wage inequality and technological change is vast. However, the perspectives taken tend to follow the skill-biased technological change hypothesis, with modelling and empirical variation on the same theme. The relationship between inequality and diffusion is taken from the perspective of the production side of the economy. The issue of how inequality influences the adoption of technologies of consumption is seldom studied and there is a clear lack of empirical models and data to illustrate it. The question is also rarely analyzed at the level of cross-country comparisons and the, possibly, more complex relationship between technological change and inequality is not commonly acknowledged. Still, as we will briefly see below, there are exceptions.

Sachs (2002) in a recent speech talked about the global innovation divide and characterized poor countries as "the excluded poor" and suggested that the international community should support their science and technology needs by doing something about those countries trapped by extreme poverty, geographical isolation and ecological distress. Similarly, Castells (1998) has identified the fourth world, as those countries that are pretty much excluded from the ICT revolution. In many different aspects, he is concerned with what has been named *the information age*. Castells believes that an escape from this fourth world (the excluded poor for Sachs) is possible, but it would require massive technological upgrading of countries, firms and households, upgrading of the educational system, establishing a world wide network of science and technology and reversing the marginalization of entire countries, cities or neighbourhoods.

Pippa Norris (2001) is preoccupied with the root causes and the consequences of the inequalities that characterized the first decade of the Internet. In relation to inequality or the digital divide as a multidimensional phenomenon, she considers three different aspects: the global divide or divergence of Internet access between developing and industrialized countries, the social divide or the gap between information rich and poor in each country, and the democratic divide, which is the difference between those who use and do not use digital resources to engage in public life. Her interest in inequalities deals with relative inequalities and whether there are special barriers to using digital technologies and if a technologies such as the Internet have similar disparities in the penetration of older communication technologies.

Hargittai (1999) looks at Internet connectivity differences across OECD countries, suggesting that even among these "more similar countries", it is possible to find differences in relation to Internet connectivity. This study indicates that there are several factors that influence the process of diffusion, among them economic indicators, human capital, the institutional legal environment, and the existing technological infrastructure. However, the empirical results demonstrate that economic wealth and telecommunications policy (understood as free competition or monopoly) are the most salient predictors of internet diffusion.

Beilock and Dimitrova (2003) proposed an exploratory model of Internet diffusion across countries and found that income per capita plays an important role in the diffusion of access, as well as infrastructure and other non economic factors.

1.5 Rationale of the Study:

This literature review allows us to make a general assessment of the current body of literature. First, there is a gap in the analyses of the impact that income inequality may have in the diffusion of new technologies, viewed from the consumption side of the economy. Second, while there are some studies that do address the issue from a viewpoint that goes beyond the skill-biased technological change hypothesis (namely about the digital divide), there is a lack of general empirical work. Since, this study aims at a macro-economic impact assessment of diffusion of ICTs in the presence of income inequalities; its aim is rather broad.

1.6. Objectives:

The aim of this study is to locate the income-inequality exacerbating aspects of diffusion of ICTs and then find out the determinants of the unequal diffusion of ICTs through a cross-country study.

1.7. Methodology and Data:

The methodology followed here is explorative mostly. We take secondary data from the published literature to explore certain conjectures hypothesised in the first chapter. For the empirical analysis, the data for diffusion and other contingent socio-economic variables have been taken from the World Development Indicators (WDI, 2003) database published by the World Bank. The methodology followed while relating the socio-economic variables and inequality measures with that of the rate of diffusion, is both ordinary least squares (OLS) estimation and generalised least squares (GLS) estimation over a simple additive regression model with diffusion rates as the dependent variables and the other socio-economic variables as the dependent variables. The data for inequality measures, besides the ones provided by GDP of each country, comes from the theil-indexed inequality database provided by University of Texas Inequality Project (UTIP). In the third chapter we have supplemented the WDI data with the data from World Information Technology and Services Alliance (WITSA) database.

1.7. Scheme of Chapters:

The first chapter gives a basic scheme to formalise the concepts of a macro-technology (GPT) and helps us conceive the diverse spectra of connected information and communication technologies under one head. Once that is done, this chapter also introduces the other conceptual categories to be used in this study. This chapter also has a selective literature review, to found the rationale for undertaking such a study as this one. Skill-bias and ICTs have been a debate for quite a long time now. The third chapter summarises the debate and also tries to lay down a framework for understanding the wage-inequality inducing tendencies of diffusion of ICTs. The third chapter is a concise exploration of the differential diffusion patterns seen across different countries, at different income-levels and different geographical settings. The fourth chapter links the effects of these income inequalities with the rate of diffusion of internet, personal computers and mobile phones (our proxies for ICTs) through a cross-country analysis. The final chapter summarises all the findings, sets the scope for future research and tries to conclude with some observations regarding the policy measures to be taken in case of ICTs.

CHAPTER-II

ICT AS SBTC[1]: ENGENDERING INEQUALITY

2.1 Situating the Problem

There is a consensus nowadays that technical change favours more skilled workers, replaces tasks previously performed by the unskilled, and exacerbates inequality. This view is shaped largely by the experience of the past several decades, which witnessed both major changes in technology, including the rapid spread of ICTs in workplaces and in our lives, and a sharp increase in wage inequality. In the U.S., for example, the college premium—the wages of college graduates relative to the wages of high school graduates— increased by over 25 percent between 1979 and 1995.[2] Overall earnings inequality also increased sharply. In 1971, a worker at the 90th percentile of the wage distribution earned 266 percent more than a worker at the 10th percentile. By 1995 this number had risen to 366 percent.[3] Many commentators see a direct causal relationship between recent technological changes and these radical shifts in the distribution of wages taking place in the U.S. economy. The title of Krueger's (1993) influential paper on computers and inequality ("How Computers Have Changed the Wage Structure") summarizes this view. Greenwood and Yorukoglu (1997)[4]similarly give a succinct statement:

> *"Setting up, and operating, new technologies often involves acquiring and processing information. Skill facilitates this adoption process. Therefore, times of rapid technological advancement should be associated with a rise in the return to skill."*

---

[1] Skill Biased Technical Change
[2] Acemoglu (2000), pp.1.
[3] Ibid pp.2.
[4] Greenwood and Yorukoglu (1997) , pp. 87

They further argue that we are now in the midst a "Third Industrial Revolution", fuelled by advances in information and communications technology, and that this revolution is responsible for the increase in inequality[5].

The view that technological developments favour skilled workers receives support from accounts of earlier episodes. For example, there were already signs of significant technology-skill complementarity in the 1910s. Goldin and Katz (1998) argue that the spread of batch and continuous-process methods of production increased the demand for skills. They add *"...the switch to electricity from steam and water-power energy sources was reinforcing because it reduced the demand for unskilled manual workers in many hauling, conveying, and assembly tasks."*[6] Over this period, capital-intensive industries increased the demand for skills considerably[7], and the scope of these industries expanded with the sharp fall in the price of electricity[8]. The rapid increase in the importance of white collar and clerical occupations gave another boost to the demand for skills. Generalizing from the experience of the 1920s, Harry Jerome (1934)[9] argued that *"...in the future...there is considerable reason to believe that the effect of further [mechanization] will be to raise the average skill required."* The early twentieth century evidence was so powerful that Griliches (1969) suggested capital and skills are intrinsically complementary. Nelson and Phelps (1967), Welch (1970), Schultz (1975) and Tinbergen (1975) also argued that technological developments increase the demand for skills. Events since then support this notion. Personal computers, computer-assisted production techniques and robotics appear to complement skilled workers, replacing

---

[5] As does Caselli (1999) in "Technological Revolutions", American Economic Review, Vol. 89. No. 1. pp. 78-102

[6] Goldin and Katz (1998), pp. 695

[7] See Goldin and Katz, (1998, Table 3).

[8] See, for example, Woolf, (1984), pp. 178.

[9] Harry Jerome (1934, p. 402)

many labour intensive tasks. In this light, it is perhaps natural to view the increase in inequality over the past several decades as a direct consequence of these technical changes.

Although the consensus is now broad, the idea that technological advances favour more skilled workers is a twentieth century phenomenon. In nineteenth century Britain, skilled artisans destroyed weaving, spinning and threshing machines during the Luddite and Captain Swing riots, in the belief that the new machines would make their skills redundant. They were right: the artisan shop was replaced by the factory and later by interchangeable parts and the assembly line.[10] Products previously manufactured by skilled artisans started to be produced in factories by workers with relatively few skills, and many previously complex tasks were simplified, reducing the demand for skilled workers.[11] Mokyr [12] describes this process vividly:

> *"First in firms, then in clocks, pumps, locks, mechanical reapers, typewriters, sewing machines, and eventually in engines and bicycles, interchangeable parts technology proved superior and replaced the skilled artisans working with chisel and file."*

Interchangeable parts were in fact very much designed to be skill-replacing. Eli Whitney, a pioneer of interchangeable parts, described the objective of this technology as

[10] See e.g., James and Skinner (1985); Goldin and Katz (1998) etc.
[11] It can be argued that technical change always increases the demand for "skills", and the artisans who were hurt as a result of new technology were not "skilled" since they lacked the flexibility to adapt to the required changes. This argument is not totally convincing, since the artisans earned considerably more than other labourers (for example, James and Skinner, 1985, report over 60 percent wage differentials for building and printing workers relative to labourers in the 1850s). So the artisans possessed skills that were being rewarded by the market, and the standardization of the production process destroyed these rewards. On the other hand, it has to be noted that many of the skill-replacing technologies of the nineteenth century may have also increased the demand for engineers and managers (see, e.g., Goldin and Katz, 1998).
[12] Mokyr (1990), pp. 137

> *"to substitute correct and effective operations of machinery for the skill of the artist which is acquired only by long practice and experience; a species of skill which is not possessed in this country[13] to any considerable extent."* [14]

The experience of the nineteenth and early twentieth centuries led Braverman (1974) and Marglin (1974) to argue that technical change was "deskilling"—a major purpose of technical change was to expand the division of labour and simplify tasks previously performed by artisans by breaking them into smaller, less skill-requiring pieces. Braverman (1974)[15], for example, suggested that the first principle of management and production techniques of the period was *"dissociation of the labour process from skills of the workers. The labour process is to be rendered independent of craft, tradition, and the workers' knowledge."* A longer view therefore suggests that technological advances do not always increase the demand for skills. In fact, most nineteenth century innovations appear to have replaced skilled workers and expanded tasks performed by the unskilled. This chapter attempts to answer why these technological advances have been skill-biased in the twentieth century, and, why these technological changes the major cause of the recent increase in inequality.

It has two main theses:

1. The behaviour of wages and returns to schooling indicates that technical change has been skill-biased during the past sixty years, and probably for most of the twentieth century. Furthermore, an acceleration in skill bias during the past few decades is the main cause of the increase in inequality.

---

[13] i.e. the USA.
[14] Quoted in Habakkuk (1962), p. 22

[15] Braverman (1974, p. 113)

2. We can understand the behaviour of technical change and its diffusion by recognizing that the development and use of technology is, at least in part, a response to profit incentives.[16] When developing skill-biased techniques is more profitable, new technology will tend to be skill-biased. Acemoglu (2000) suggests that the nineteenth century was characterized by skill-replacing developments because the increased supply of unskilled workers in the English cities (resulting from migration from rural areas and from Ireland) made the introduction of these technologies profitable. In contrast, the twentieth century has been characterized by skill-biased technical change because the rapid increase in the supply of skilled workers has induced the development of skill-complementary technologies. The recent more rapid skill-biased technical change is in turn likely to have been a response to the acceleration in the supply of skills during the past several decades.

Finally, we conjecture that the rapid diffusion of the recent technological developments (i.e. the ICTs) are likely to have affected the organization of the labour market—including the way firms are organized and the form of labour market institutions— and may have had a large effect on the structure of wages through this channel.

In the process of developing this argument, this chapter sets out a simple theoretical framework[17], in which inequality and returns to skills are

---

[16] Precedents of this approach include Schmookler (1966), who emphasized demand pull and the extent of the market as key determinants of innovations; the endogenous growth theory, e.g., Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992); the induced innovation theory, including Ahmad (1965), Kennedy (1964), Samuelson (1970), Hayami and Ruttan (1970), and David (1975); and recent work including Acemoglu (1998, 1999b, 2000), Acemoglu and Zilibotti (1999), and Kiley (1999).

[17] Alternative hypotheses of the increase in the wage inequalities include the globalization of the world economy, changes in labour-market institutions, and the appearance of winner-take-all markets. For surveys of this literature, see the symposium in the Spring 1997 issue of the Journal of Economic Perspectives.

determined by supply and demand forces (technology).[18] Using this framework as a unifying device, we critically survey many of the theories that explain the recent increase in inequality by technological factors, and discuss how various pieces of evidence can be interpreted within this framework.

2.2. Wages and Productivity

We begin with a discussion of what underlies the wage gap—that difference in wages between high- and low-skilled workers. In reality, of course, there is a continuum of worker skills, and while economic models can accommodate this concession to reality, the intuition is clearer in a simpler model.

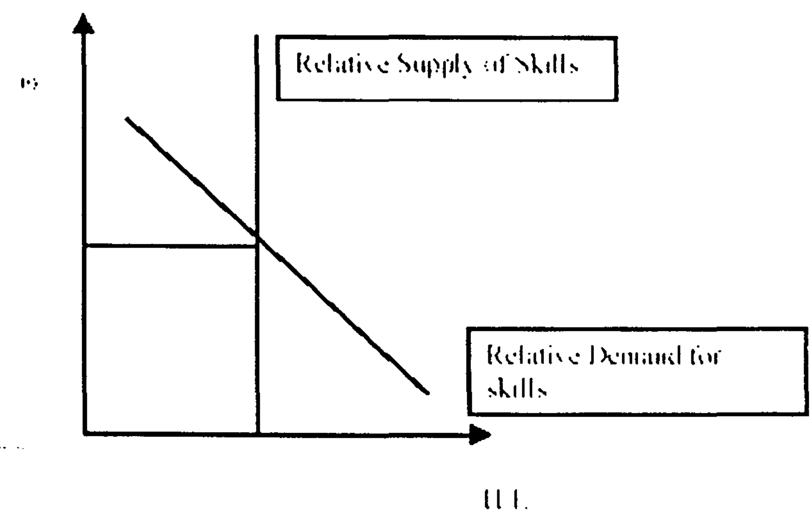
Suppose then that there are just two types of workers, high-skilled (H) and low-skilled (L). Each type of worker is paid according to the value of their marginal product. To keep things simple while still allowing the ideas to get across, assume that there is just one product produced and that production of this product requires skilled and/or unskilled labour. The two types of labour are substitutable for one another although high and low skilled workers are not perfect substitutes. Assuming that H-workers, who can produce more, earn more, the skill premium is just the wage of the H workers relative to the wage of the L workers. Denote this skill premium by ω. The larger the wage of high-skilled workers relative to low-skilled workers, the bigger will be ω. It will be a function of the marginal productivity of H, the marginal productivity of L, and the elasticity of substitution between the two types of labour.

Wages depend on the marginal productivity of the different types of labour. A higher marginal product means a higher wage. Technology matters here in that technology enhances the productivity of workers. If there is no skill-bias

[18] Precedents of the supply and demand approach include, among others, Becker (1964), Welch (1970) and Tinbergen (1975).

to technology, the marginal productivities of H and L are equally impacted by a new technology. If the change in technology makes H workers more productive relative to what it does for L workers, then there is skill-biased technical change.

The degree to which skilled and unskilled workers can substitute for one another also is going to matter when we think about what skill biased technical change will do to relative wages. In the usual case, H and L workers will be imperfect substitutes for one another (so that, economists call the elasticity of substitution between worker types is greater than one.) In this case, we can use a simple diagram to get across some important ideas.

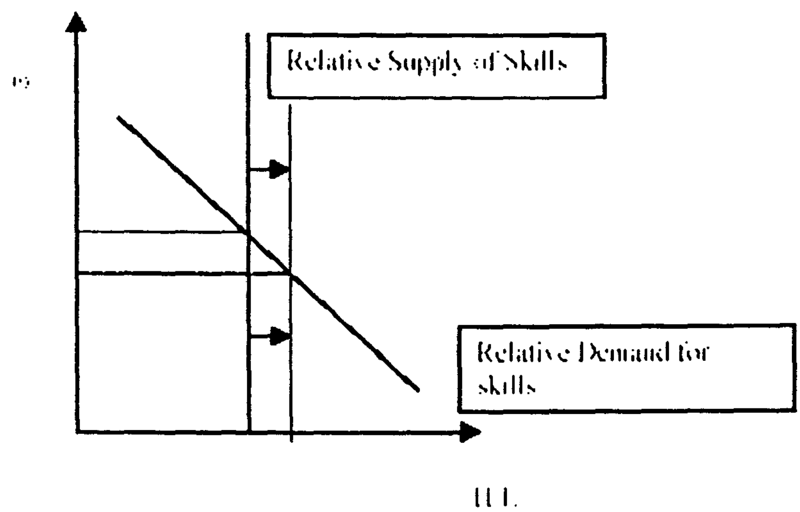


In the above diagram[19], the skill premium is on the vertical axis. Recall, as the wage of skilled to unskilled labour gets larger, ω increases. On the horizontal axis is the relative supply of skilled to unskilled labour. This is a short run diagram in that the relative supplies of the two types of workers are fixed. That is, even if the relative wage of H workers goes up, in the short run, there will not be more H workers (although over a longer run one would expect workers to respond to this incentive and on the margin some L workers

[19] This diagram is from Acemoglu (2000)

would engage in more training.) The relative demand for skills is downward sloping. One way to think about this is to note that as H workers become relative more expensive, for given levels of productivity, H workers are less attractive to employers and firms will substitute toward L workers. This is a movement towards the origin on the H/L axis.

With this simple set-up, we can examine several interesting and relevant scenarios. Suppose, for example, that the relative supply of skilled workers were to increase. This would shift the relative supply curve to the right and, all else remaining equal; the relative wages of skilled workers would fall.



In fact, workers in the U.S. have become more highly trained over the past few decades.[20] But while the relative supply of skilled workers has increased, the relative wage of skilled workers has increased, not decreased. This puzzle is clearly illustrated by the following figure from Acemoglu (2000).

[20] A number of facts regarding these changes are available in "Computing Inequality: Have Computers Changed the Labour Market?" by David Autor, Alan Krueger, and Lawrence Katz (available in WP version at www.nber.org/papers/W5956)

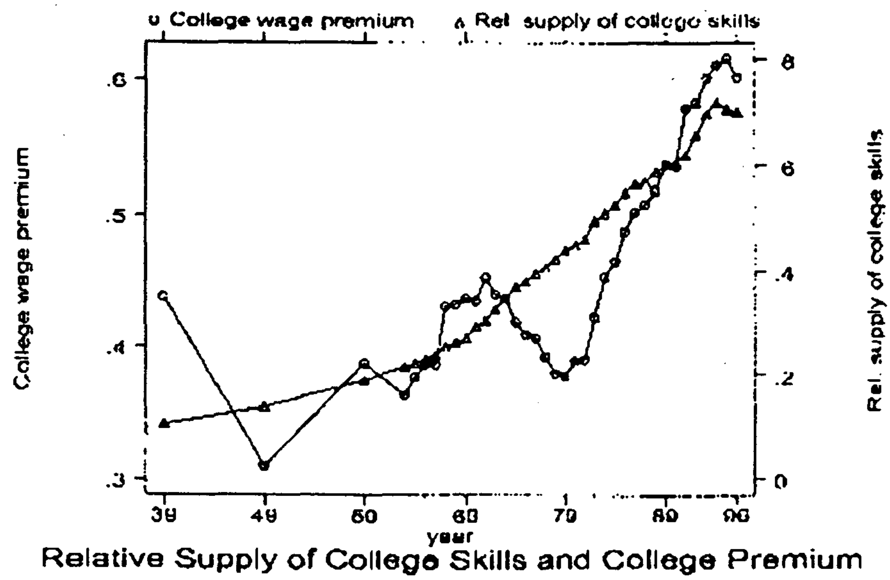
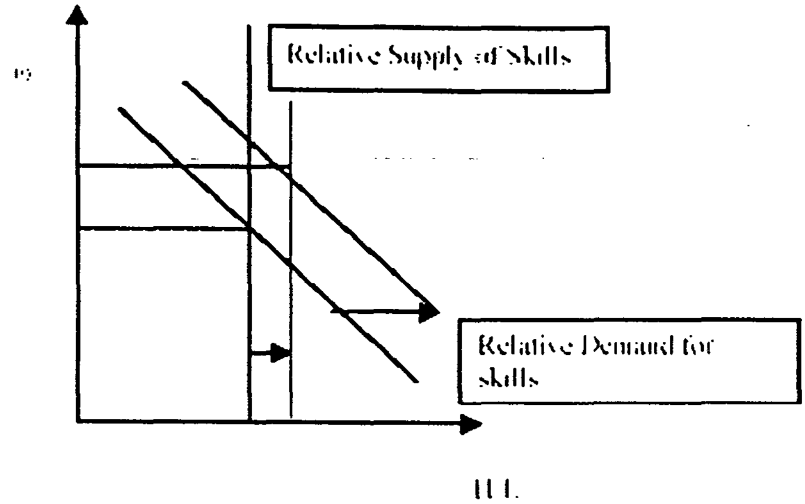


Figure 1: The behavior of the (log) college premium and relative supply of college skills (weeks worked by college equivalents divided by weeks worked of noncollege equivalents) between 1939 and 1996. Data from March CPSs and 1940, 1950 and 1960 censuses.

Figure 1.

With the relative supply of skilled workers going up and their relative wage also going up, we are left either concluding that the model is dead wrong or something else has changed. Over the last few decades, technology has changed. In particular, ICTs have become ubiquitous. While we'll look at the evidence on this below, consider for now how such a change would enter into our diagram. If ICTs were to make skilled labour relatively more productive, it would increase the relative demand for skilled labour at any given relative wage. In our diagram, this can be illustrated with a shift to the right of the relative demand schedule:



By considering both an increase in the relative supply of skilled labour and skill-biased technical change at the same time, our simple model illustrates that the net result can be an increase in the relative wage of skilled workers. This diagram explains what has happened over the last few decades. It is a story in which the relative wages of unskilled labour have fallen. It is also a story with absolutely no international trade component. In this way, skill-biased technical change can, within the context of a simple and not particularly objectionable economic model, explain the same phenomenon that is sometimes attributed to increased trade with low wage countries.[21]

2.3 Evidence

Measuring skill biased technical change is, in principle, straightforward. A first place to turn is the large literature on estimating production functions. If the diffusion of underlying technology is changing in a way that rewards skilled labour relatively favourably, this will show up in shifts in those production function parameters that are related to the marginal productivity

---

[21] See Fagerberg Jan, (Sep., 1994), Technology and International Differences in Growth Rates, Journal of Economic Literature, Vol. 32, No. 3., pp. 1147-1175.

of factors. This, though, is not how the vast majority of the empirical literature on skill-biased technical change has progressed. This could be in part because doing this carefully requires hard-to-obtain plant-level data on production. Instead, the most common approach to measuring skill-biased technical change seems to be to use industry-level data on the ratio of skilled labour to unskilled labour (or non-production workers relative to production workers).[22]This is troublesome. As Gordon Hanson and Robert Feenstra as well as others have pointed out, the ratio of skilled to unskilled workers might increase for reasons that have nothing to do with skill-biased technical change. In particular, the huge growth in outsourcing will lead to an increase in this ratio as non-skilled jobs are moved abroad. Skill-biased technical change is taken to reflect unskilled-labour saving technical change. Outsourcing, while empirically important and observationally equivalent in the aggregate data, seems to be a different phenomenon.

We begin with a set of stylized facts. Since the effect of new technology on the distribution of wages in the recent past is central to the focus here, we concentrate around a number of salient facts from the post-war U.S. economy.[23] Briefly, these facts are:

1. The past sixty years have seen a large increase in the supply of more educated workers, while returns to education have risen.

2. Returns to education fell during the 1970s, when there was a very sharp increase in the supply of educated workers. Returns to education then began a steep rise during the 1980s.

3. Overall wage inequality rose sharply beginning in the 1970s. Increases in within group (residual) inequality—i.e., increases in inequality among observationally equivalent workers— account for much of this rise.

---

[22] See, for example, Eli Berman (1998)

[23] The discussion is limited to the major trends in the U.S. economy because of there is notably more research to build upon.

4. Average wages have stagnated and wages of low-skill workers have fallen in real terms since 1970.

We argue that technical change over the past sixty years, or even over the past century, has been skill-biased. This conclusion follows from fact 1 above: in the absence of substantial skill bias in technology, the large increase in the supply of skilled workers would have depressed the skill premium.

In 1970, Welch [24]reached the same conclusion, and argued:

> *"With the phenomenal rise in average education, why have rates of return failed to decline?...It is obvious that changes have occurred to prevent the decline in returns to acquiring education that would normally accompany a rise in average educational level. Presumably, these changes have resulted in growth in demand for ... education... sufficient to absorb the increased supply with constant or rising returns."*

The 30 years after Welch wrote these words witnessed a much more rapid increase in the supply of education, and a sharp increase in the returns to more skilled workers, suggesting that skill-biased changes in technology continued throughout the post-war period.

And yet, if technical change has been skill-biased throughout the recent past, why did inequality increase during the past 30 years, but not before? There are at least two possible answers to this question. The first, which Acemoglu(2000) calls the steady-demand hypothesis, maintains that demand for skills increases at a constant pace, so changes in inequality must be explained by the pace of the increase in the supply of skills. According to this hypothesis, inequality was relatively stable before the 1970s, because the rate of skill accumulation in the U.S. economy was more rapid than the constant

---

[24] Welch (1970, p.36)

pace of skill-biased technical change[25]. The recent increase inequality is then explained not by a major technological change, but by a relative slowdown in skill accumulation. The second possible answer comes from the acceleration hypothesis, which maintains that there has been an acceleration in skill bias beginning in the 1970s or 1980s. According to this hypothesis, there has been a notable acceleration in the demand for skills, driven in large part by advances in information technology, and perhaps even approaching the scale of a "Third Industrial Revolution".[26]

One approach would view technology as exogenous, stemming from advances in science or from the behaviour of entrepreneurs driven by a variety of non-profit motives. Demand for skills increased faster during the past thirty years, this approach would maintain, because of a technological revolution led by the microchip, personal computers and the Internet.[27] New technologies of the nineteenth century were not skill-biased because the technological frontier then only enabled the invention of skill-replacing techniques.

Yet, there are a number of problems with this approach. First, although a number of papers, including Greenwood and Yorukoglu (1997), Hornstein and Krusell (1997), and Galor and Moav (2000), show that rapid technical change may lead to slower total factor productivity (TFP) growth, the slow rates of TFP and output growth of the past several decades are difficult to reconcile with a technological revolution during this time period. Second, demand for skills appears to have accelerated starting in the late 1970s,

---

[25] See, e.g., Katz and Murphy, (1992)

[26] This is akin to the formulation of "Technological Revolutions" by caselli (1999).

[27] See, among others, Krueger (1993), Berman, Bound and Griliches (1994), and Autor, Katz and Krueger (1998) for evidence that the rapid spread of computers has increased the demand for skills. See Krusell, Ohanian, Rios-Rull and Violante (2000), Galor and Tsiddon (1997), Greenwood and Yorukoglu (1997), Aghion and Howitt (1998, chapter 9), Caselli (1999), Galor and Moav (2000), Violante (1999), Rubinstein and Tsiddon (1999), Aghion, Howitt and Violante (1999), and Gould, Moav and Weinberg (1999) for models in which rapid technical change increases the demand for skills and causes a rise in inequality.

precisely when the supply of skills increased very rapidly. Exogenous technology theories do not explain the timing of this acceleration.[28] An alternative theory maintains instead that new technologies are endogenous and respond to incentives. It was the large increase in the supply of skilled workers, these approach claims, that induced the acceleration in the demand for skills. The reasoning is as follows. When skill-biased techniques are more profitable, firms will have greater incentives to develop and adopt such techniques. A key determinant of the profitability of new technologies is their market size; machines that can be sold in greater numbers will be more profitable. Schmookler (1966), in his pioneering study, Invention and Economic Growth, placed great emphasis on market size.

He argued[29]-

> *"invention is largely an economic activity which, like other economic activities, is pursued for gain;... expected gain varies with expected sales of goods embodying the invention."*

This reasoning implies that machines complementary to skilled workers will be more profitable to develop when there are more skilled workers to use them. New technologies have become more skill-biased throughout most of the twentieth century because the supply of skilled workers has grown steadily. This perspective also suggests that a faster increase in the supply of skills can lead to an acceleration in the demand for skills (Acemoglu, 1998). So the timing of the increases in supply and demand is not a coincidence—instead, it reflects technology responding to the supply of skills. In this

[28] Naturally, supply and demand may have moved together because supply responded to demand. We argue below that the large increase in the supply of educated workers was not in anticipation, or in response to, high returns, but driven by a variety of other factors. More generally, we focus on the effect of the supply of skills on technology not because we view supply as exogenous, but simply because the effect of supply on technology is more important in understanding the questions posed above.

[29] Schmookler (1966), pp. 206.

theory, rapid skill-biased technical change is not necessarily associated with rapid overall technical progress.

2.3.1 Cross-country patterns:

So far, we have focused on U.S. wage inequality patterns and incentives to develop new technologies coming from the U.S. supply of skills. The cross-country dimension presents a number of challenges. First, it is difficult to explain why inequality increased much more in some countries than others. Second, when there are many countries in the world economy, whether it is the relative supply of skills in each country or in the world as a whole that determines the direction of technical change, poses a problem.

Differences in inequality patterns:

Although the tendency towards greater inequality has been a feature in many developed and LDCs[30] there are also marked differences in the behaviour of within and between-group inequality across these countries. Katz, Blanchffower, and Loveman (1995) and Murphy, Riddell, and Romer (1998) show that the differential behaviour of the supply of skills can go a long way towards explaining the differences in the returns to schooling, especially between the U.S., Canada and the U.K. Nevertheless, it is puzzling that wage inequality increased substantially in the U.S. and the UK, but remained fairly stable in many continental European economies.[31]

The standard explanation for this divergent behaviour, succinctly summarized by Krugman (1994) and OECD (1994), and sometimes referred to as the Krugman hypothesis, maintains that inequality did not increase as much (or not at all) in Europe because labour market institutions there

[30] See Freeman and Katz (1995), and Berman and Machin, (2000)
[31] See, for example, Davis (1995),or Gottschalk and Smeeding (1999)

encourage wage compression, limiting the extent of inequality. The view that wages are more compressed in Europe clearly has some merit. Blau and Kahn (1995) show that the major difference in overall inequality between the U.S. and many continental European economies is not in the 90-50 differential, but in the 50-10 differential. This suggests that the minimum wage, strong unions, and generous transfer programs in Europe are in part responsible for the relative wage compression in Europe.

Nevertheless, the Krugman hypothesis runs into two difficulties. First, unless there are extremely rigid institutions that fix the skill premium exogenously, skill-biased technical change should increase wage inequality irrespective of the degree of exogenously imposed wage compression. In contrast, in many continental European economies, most notably in Germany, wage inequality was very stable.[32]

Second, the Krugman hypothesis makes an explicit prediction: to the extent that wage compression is preventing the increase in the inequality of wages, profit maximizing employment decisions of firms should lead to a large decline in the employment of unskilled workers relative to that of skilled workers. In fact, skill-biased technical change might even reduce the unemployment rates of skilled workers. Yet, in Europe, the unemployment of skilled and unskilled workers increased together[33], and unskilled employment did not grow faster in the U.S. than in European economies (Card, Kramartz and Lemieux, 1996, Krueger and Pischke, 1997).

It is possible that bargaining arrangements in Europe between firms and unions, imply not only wage compression. This can be because European institutions may be forcing firms to pay uniform wages to all educated workers irrespective of their exact contribution, making the employment of

[32] See, e.g., Freeman and Katz, (1995)
[33] See, e.g. Nickell and Bell, (1996), Krueger and Pischke, (1997)

skilled workers less profitable as well. Alternatively, if unions represent both skilled and unskilled workers, and are committed to wage compression, they may not want to suffer a large decrease in the employment of unskilled workers. So they may be willing to make certain concessions in wage levels in order to induce firms to employ more unskilled workers at a compressed wage structure. It is also useful to bear in mind that European economies, as the U.S., are likely to have experienced skill-biased technical change not only during the past thirty years, but for much longer. So how continental European economies responded to the more recent wave of skill-biased technologies cannot be analyzed in a vacuum.

An alternative view suggested by Nickell and Bell (1996) explains the differences in the wage structure across countries by differences in the skill distribution. According to this view, because of the relative weakness of the U.S. high school system, American non-college workers are less skilled than their European counterparts. However, recent work by Devroye and Freeman (2000) shows that differences in skill distribution have little to do with cross-country differences in wage dispersion. They document that dispersion of internationally comparable test scores among native born Americans are very similar to those in Europe, but wage inequality among native born Americans is much higher. Moreover, the Nickell-Bell approach also fails to explain the differential changes in inequality: the U.S. was roughly as unequal as France in the 1970s, and the relative test scores of American youth have not deteriorated since then.

2.3.2 International determinants of technology

There are a number of interesting and difficult issues that arise when we consider the international dimension. Here I simply mention some preliminary approaches, but clearly much theoretical and empirical work remains to be done.

A first extension of the endogenous[34] technology idea to an international context might be to suppose that skill bias in each country is determined by the country's relative supply of skills. However, there are reasons to expect that new technologies will spread across countries. In this case, it may be the incentives in the technologically most advanced country (the technological leader) that determine the skill bias of world technologies. This description may be adequate for understanding the skill bias of technologies used by less developed countries (see for example Acemoglu, 1999b). It is also possible for other technologically advanced economies to pursue a different path of technological development than the leader, in which case domestic incentives may be important in shaping skill bias.

What determines the skill bias of technologies developed by the technological leader, depends on the market sizes for different types of technologies, hence on the international enforcement of intellectual property rights. For example, in the discussion on the effect of trade on technology, Acemoglu (2000) supposed that there were no intellectual property rights for U.S. companies enforced in less developed economies. In this case, incentives to develop new technologies are shaped by the U.S. domestic supplies. This may be a good starting point, since even when property rights are enforced, there will be a number of difficulties facing U.S. companies marketing their technologies in other countries. For example, technologies may need to be adapted to

[34] Endogenous technical change assumes that technical change is just like any other factor of production, and not exogenously determined as in the classical and neo-classical models.

conditions in local markets, or producers in least developed countries (LDCs) may be unable to pay for these technologies because of credit problems.

It is also worth noting that even when a country is using U.S. technologies, its effective skill bias may be influenced by its domestic skill supply. This is because U.S. technologies need to be adapted to local conditions, and firms will have a greater incentive to do this when there is a larger supply of workers to use these technologies. So it may be not only technological change that is endogenous to relative supplies, but also technology adoption.

Finally, another interesting cross-country dimension comes from looking at wage inequality trends in LDCs. The first order predictions of the standard trade theory are not borne out: instead of a decline in inequality, which would have been expected due to the greater integration of these economies into world trade, inequality increased in most LDCs. The recent paper by Berman and Machin (2000) shows an interesting pattern: while there has been rapid skill upgrading in many middle income countries, there is much less evidence for rapid skill upgrading in the poorest economies. A possible explanation for these patterns is that middle income countries are adopting advanced technologies much more rapidly than the poorest countries, and since these technologies are more skill-biased, these economies are undergoing rapid skill upgrading and increases in inequality. Furthermore, if, as claimed by Acemoglu and Zillibotti (1999), ICTs developed in the rich economies are typically "too skill-biased" for LDCs, the recent acceleration in skill bias could have negative implications for the LDCs. More generally, the impact of technologies developed in the advanced economies on LDC labour markets is an area that requires further research.

2.4. Conclusions

One of the over-arching questions that much of the research has tried to address is how important skill-biased technical change has been in explaining wage inequality. Definitive answers are few. This is a very puzzling literature. From a theoretical point of view, there is debate over whether in an international economy skill-biased technical change should matter. The answer depends on the assumptions of the underlying model. As a purely intellectual exercise, one can find convincing arguments from both the camps. From an empirical point of view, results are disappointing. Starting from Bound and Johnson, who were one of the first to address the question, and subsequently in much of the empirical work that followed, researchers lost track of the different competing theories[35] and instead focused only on examining one explanation for the wage gap. In terms of important unanswered empirical questions, re-visiting the role of skill-biased technical change in a framework that allows trade and other plausible explanations seems like a potentially important research agenda.

Autor, Katz, and Krueger wrote that "Skill-biased technical change is the "natural" name for economists to attach to *unexplained* within-sector and within-firm growth in the demand for skills"[36].But it remains the case that outsourcing as well as the changing composition of output within a sector (or firm) are also "natural" names to attach to unexplained within-sector and within-firm growth in the demand for skills. Also, this hypothesis has to contend with the question of the incommensurate skill demand with its effective use over the years.

---

[35] In fact, as Di Nardo and Pischke (1997) have shown, the causal effects of ICTs (computers) on wages is not straightforward. Applying similar statistical techniques to Krueger(1993), they have shown that wage differentials associated with the use of calculators, a telephone, a pen, or a pencil, or even sitting on the job, are very similar to those measured by computer sue. Instead, their results suggest that computer users have unobserved skills which may have little to do with the use3 of computers but are rewarded in labour markets, or that computers were introduced in jobs that were already of higher wages.

[36] Italics added

CHAPTER-III

DIFFERENTIAL DIFFUSION OF ICT: A BRIEF SURVEY

3.1 INTRODUCTION:

The average incomes in the world's richest countries are over twenty times higher than those in the world's poorest countries. As information and communication technologies (ICT) are the current manifestation of the ongoing sequence of technological revolutions, ICT can be seen as the key factor driving economic growth in the present-day industrial societies. From the viewpoint of the world's poor, the problem is that differential access to ICT is even more pronounced than national income inequalities across the world. Consequently, there is concern that ICT is becoming a factor, which contributes to the widening of income differentials between countries.

There is indeed increasing evidence that ICT investment is associated with an improvement in both firm and macroeconomic performance in the leading industrial countries, especially in the United States. However, studies that look at larger samples of countries find little correlation between ICT investment and overall productivity in the rest of the world (Pohjola 2002). One possible explanation for this apparent 'productivity paradox[1]' is the fact that not many countries, other than the US, have yet invested much in ICT.

---

[1] Which is derived from the famous quote of Solow (1957), the famous neo-classical economist where he says "you can find computers everywhere but productivity statistics", which came to be known as the Solow productivity paradox.

To bring about a convergence in income levels across countries, the factors, which equalize differences in technology adoption and diffusion across countries, need to be identified. In particular, to be able to take actions aimed at bridging the 'digital divide' or at eradicating 'information poverty', it is important for policy-makers to know what factors explain the differences across countries in the adoption and diffusion of ICT.

In principle, equalizing the differences in technology should be easier than levelling the disparities in physical and human capital. Unlike physical goods and human capital, ideas are non-rival in the sense that their use by one person or by one country does not prevent others from using them. Once invented, they can be copied and transferred at negligible costs. Given that digital goods have exactly the same properties as ideas, the same conclusion should also hold for goods and services that can be expressed in binary bits of logic such as computer software, scientific databases and libraries, media entertainment, and Internet delivery of goods and services (Quah 2001). This means that at least some components of ICT should be as easily transferable from one country to another as ideas.

In practice, however, technology is to a substantial degree local, not global. Keller (2001) has shown that geographic distance matters for the international diffusion of technology. He estimated for a group of OECD countries that the productivity effects of R&D decline with the distance between sender and recipient countries. The distance at which the amount of spillovers is halved is about 1,200 kilometres. Interestingly, however, the absolute value of the distance parameter has declined substantially between the mid-1970s and the 1990s. This implies that technological knowledge has become less country-specific. Increasing use of ICT may be one of the factors explaining this trend.

Given that economic growth is driven by advances in technology, those countries that are behind the technological curve can improve their growth performance simply by adopting the technologies created by others. Imitation is less costly than innovation. This highlights the need for the transfer of technology from the frontier countries to the less developed ones. It also directs attention to the patterns of interaction and communication between a developing country and the rest of the world. ICT plays a dual role here. It is part of the technology stock on the one hand and it provides a channel for technology transfer on the other.

The persisting income disparities across countries indicate that technology does not diffuse automatically. The speed and extent of diffusion depend on the capacities of the receiving countries to absorb the new ideas about how to produce more efficiently. These capacities, in turn, depend on factors such as income, education, openness to new ideas, property rights and the cost of access to technology. At least some of these determinants can however be influenced by proper policies.

The components of ICT to be covered in the analysis include computer hardware, software, services and telecommunications including the Internet. A simple statistical model is also estimated to identify the most important determinants of real spending on computer hardware in a panel of 49 countries in the period 1993-2000.

3.2 ACCESS TO ICT INFRASTRUCTURE

The New Economy can be given many definitions, but the one element they all must have in common is the view that the world economy is undergoing a fundamental structural change driven by the revolution in information and communication technology. Its defining characteristics are the fast improvement in the quality of ICT equipment and software, and the concomitant sharp decline in their quality adjusted prices. Rationally behaving households, business firms, schools and governments respond to the change in relative prices by substituting ICT equipment, software and services for other goods and services.

Table 3.1

Information and communication infrastructure in the 1990s
(per 1,000 people)

	Personal computers		Internet users		Telephone Mainlines		Mobile phones	
Country groups[1]	1995	2001	1995	2001	1990	2001	1995	2001
Income breakdown								
High-income OECD	188	363	34	360	455	574	89	690
Developing countries	14	34	2	37	52	104	4	94
Least developed	..	4	..	3	3	7	0	8
Region breakdown								
Northern America	273	623	68	467	555	660	108	382
Western Europe	174	325	30	345	445	572	84	747
East Asia and Pacific	82	158	14	177	148	222	36	278
Eastern Europe and Central Asia	26	81	5	65	130	232	4	199
Middle East and North Africa	28	62	1	61	89	147	16	163
Latin America and the	17	49	1	63	66	145	9	142
Caribbean	..	12	..	9	9	19	1	30
Sub-Saharan Africa	0	4	0	4	5	20	1	9
South Asia								
Notes: .. = data not available,	0 = less than half the unit shown.							

[1] The classifications are based on the definitions in the World Bank's Development Indicators Database, but all countries with population below one million are excluded. The group average has been calculated when data for at least half of the countries Are available.

Source: WDI (2003)

Table 3.1 presents information about the number of personal computers (PCs), Internet users, telephone mainlines and mobile phone subscribers per 1,000 people across the world. The differences between the displayed groups of countries are striking. In the rich OECD countries the PC and Internet densities are ten times higher than in developing countries but roughly 100 times higher than in the least developed countries. Also, the rich countries have 6-7 times more telephone mainlines and mobile phone subscribers per capita than the developing countries but 80 times more than the least developed countries. Although the relative digital divide is becoming narrower over time, the absolute differential is increasing. Consequently, if the presence of the New Economy can be measured by the use of ICT equipment, there cannot exist many—if any—new economies outside the group of high-income OECD countries.

The lower panel of Table 3.1 divides the world into geographical regions which are ranked here on the basis of the number of personal computers per 1,000 people in 2001. But the ranking would be nearly the same if Internet users or main telephone lines were used instead of PCs. Northern America is at the top of the list, followed by Western Europe and by East Asia and the Pacific. Sub-Saharan Africa and South Asia lie at the bottom. If the regions were ranked according to mobile phone density, then Western Europe would overtake Northern America as the leading group. This reflects the well-known difference in ICT specialization between these regions.

The contrasts in the access to the ICT infrastructure are as stark between the geographical regions as between the income groups. Whereas there are only 30 times more telephone mainlines per 1,000 people in Northern America than in South Asia, this discrepancy is much greater for PCs and Internet users: 160 and 120, respectively. In Western Europe the mobile phone density is 80 times higher than in South Asia.

Table 3.1 also highlights the rapid growth in the use of computers, the Internet and mobile phones in the 1990s. In developing countries, the number of personal computers per capita increased twofold, whereas the Internet and mobile phone densities rose 20-fold in the second half of the 1990s.

The Internet is of special interest here as it is believed to integrate markets and to link together people across all kinds of traditional boundaries. Among other things, it can be regarded as the first truly global marketplace. A recent survey of the Internet domain name system indicates that in July 2002 there were 162 million computer hosts on the Internet. A host is a computer that has users who access network services through it. The growth in the number of Internet hosts has been spectacular, as in January 1991 their number was only 376,000. Of all the people using the Internet regularly, approximately 30 per cent reside in Canada and the United States, 32 per cent in Europe and 31 per cent in the Asia-Pacific region. This means that only 7 per cent of them come from the rest of the world, namely from Africa, the Middle East and Latin America. As shown in Table 3.1, while every second person is 'online' in North America, only four persons in a thousand are connected to the Internet in South Asia and nine in a thousand in Africa.

Thus although the Internet integrates markets and joins people, it does this at disparate rates across the world. People in the rich countries, having the required infrastructure and skills, seem to be in a much better position to benefit from this current, Internet-driven phase of globalization than people in the poor countries.

3.3 PATTERNS OF ICT SPENDING

Table 3.2 displays the average GDP shares of the ICT components for the 51 countries in 1993-2001. Unfortunately, data for earlier years are not available. As shown, the total ICT spending share has risen from 4.4 per cent in 1993 to 7.3 in 2001. It is quite equally split between spending on information technology and spending on telecommunication which comprises public and private network equipment and telecommunication services. IT hardware is the largest IT spending component, accounting for 0.8 per cent of GDP in 1993 and 1.1 per cent in 2001. Both IT services and software seem to have increased in importance over the period. The former accounted for 0.9 and the latter 0.5 per cent of GDP in 2001. The spending share of other office equipment (typewriters, calculators, copiers etc.) has been rather small and stayed constant at 0.1 per cent.

Table 3.2
Average GDP shares of ICT spending, of 51 countries, (1993-2001)

	1993	1994	1995	1996	1997	1998	1999	2000	2001
IT hardware	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.2	1.1
Office equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Software	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
IT services	0.5	0.5	0.5	0.5	0.5	0.7	0.8	0.8	0.9
Internal spending	0.9	0.8	0.7	0.7	0.7	0.8	0.8	0.9	0.9
Total IT	2.5	2.4	2.3	2.4	2.6	2.8	3.1	3.4	3.6
Telecommunication	2.0	2.0	2.1	2.3	2.4	2.8	3.2	3.4	3.7
Total ICT	4.4	4.5	4.5	4.7	5.0	5.6	6.2	6.8	7.3

Sources: WITSA (2002)[2] for the ICT spending data, IMF (2002) for the GDP data

The WITSA data on hardware, software and services spending cover the purchase of these items from external agents or corporations. While this external spending includes the tangible portion of the IT market, internal

[2] World Information Technology and Services Alliance (WITSA)

spending is made up of the intangible portion, i.e. of expenses that cannot be attributed to a vendor. As shown in Table 3.2, its GDP share has been rather constant, 0.7-0.9 per cent, in the period considered.

In Table 3.3 the 51 countries for which data exist are classified into two groups: those above and those below the average spending ratio of 5.4 per cent over the period 1993-2001. New Zealand, Sweden, Australia, Switzerland and Singapore are at the top of the ranking whereas Romania, Saudi Arabia/Gulf States, Egypt, Indonesia, and India are at the bottom. Disparities in ICT spending ratios are quite large, ranging from 1.5 per cent in Romania to 10.3 per cent in New Zealand. It is interesting to observe that a significant 'digital divide' exists even between the European Union countries as can be seen by comparing Sweden and United Kingdom at the top of the list with Spain and Greece at the bottom. Two developing countries—South Africa and Colombia—stand out from the rest with spending shares of 7.1 and 7.0 per cent, respectively. These countries have spent a larger share of their national income on ICT than, for example, Finland and Germany.

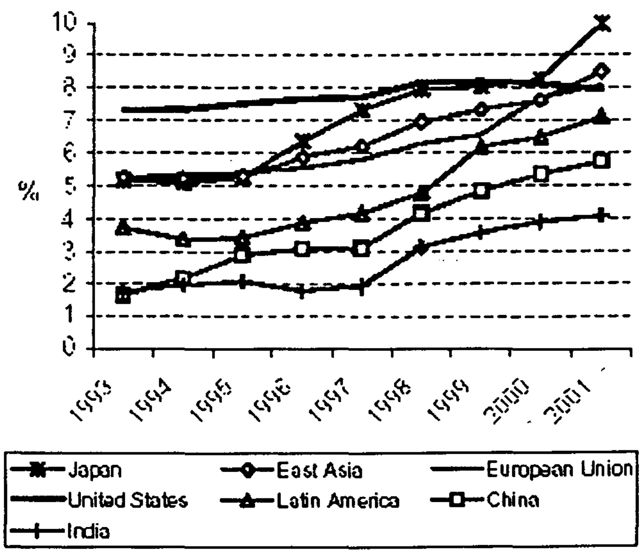
Table-3.3
Average share of ICT spending in gross domestic product, 1993-2001

Countries above average	%	Countries below average	%
New Zealand	10.3	Brazil	5.4
Sweden	8.8	Portugal	5.1
Australia	8.7	Vietnam	4.7
Switzerland	8.4	Italy	4.6
Singapore	8.3	Taiwan	4.6
United Kingdom	8.0	Greece	4.4
United States	7.8	Spain	4.2
Canada	7.7	Venezuela	3.9
Netherlands	7.5	Slovenia	3.7
Denmark	7.3	Poland	3.7
Hong Kong	7.2	China	3.7
South Africa	7.1	Argentina	3.6
Japan	7.1	Mexico	3.5
Colombia	7.0	Turkey	3.3
France	6.9	Bulgaria	3.1
Czech Republic	6.8	Philippines	3.1
Israel	6.6	Thailand	3.1
Belgium	6.5	Russia	2.9
Finland	6.4	India	2.7
Hungary	6.2	Indonesia	2.1
Germany	6.2	Egypt	2.1
Norway	6.1	Saudi Arabia/Gulf States	1.8
Ireland	5.8	Romania	1.5
Malaysia	5.8		
Korea	5.8		
Austria	5.6		
Slovakia	5.5		
Chile	5.5		
Source: WITSA (2002) for the spending data; IMF (2002) for the GDP data			

Figure 1 takes a look at the interesting change in the spending ratios that has taken place over the period covered by the data. As there are too many countries to be displayed in one diagram, comparisons are made between larger countries and groups of countries only. The East Asian group consists of Hong Kong, Korea, Singapore and Taiwan. The European Union denotes its member states, excluding Luxemburg.

Latin America stands for those countries from this continent which are included in the dataset (i.e. Argentina, Brazil, Chile, Colombia, Mexico, and Venezuela). The average share of ICT spending in GDP is presented for each group. It is surprising to find out that Japan, East Asia and the European Union have caught up with, and have even overtaken, the United States in the ratio of ICT spending to GDP. Latin America and China are also rapidly approaching the US level, whereas India's convergence seems to be much slower. It is also noteworthy that the other countries have started to approach the US level only rather recently, in the second half of the 1990s. The privatization of the Internet in the mid-1990s is one possible explanation for this rapid increase in ICT spending, the Y2K[3] problem may be another.

Figure 1
Shares of ICT spending in GDP, 1993-2001



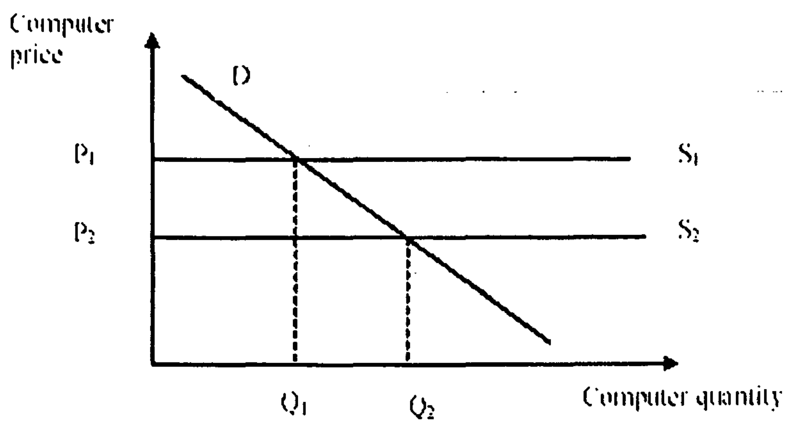
Source: WITSA (2002) for the spending data; IMF (2002) for the GDP data

[3] Y2K problem was encountered by the computers which were programmed to synchronise files with two-digit years, which failed to operate when confronted with data from the millennium- after.

2.4 EXPLAINING THE ADOPTION OF ICT

There are numerous variables which can be thought of as having an influence on them. A simple demand and supply framework, borrowed from Gordon (2000), is therefore helpful in highlighting the most important determinants of ICT use. Figure 2 presents a standard downward-sloping demand curve D for a component of ICT, say, the computer, and two supply curves, S1 and S2. The supply curves have been drawn as horizontal lines to illustrate the fact that the marginal costs are small in computer production. Technological progress in the computer component manufacturing industry causes the supply curve to fall steadily from S1 to S2. P's and Q's denote the corresponding equilibrium prices and quantities.

Figure 2
Supply and demand for computers



The fast technological progress in the manufacture of ICT equipment has been and still is the key factor increasing the supply and reducing the price of ICT. This technological revolution started with the invention of the transistor in the late 1940s. It is a semiconductor device that acts as an electrical switch and encodes information in binary form. Integrated circuits, consisting of a large number of transistors, were introduced in the late 1950s. They were originally developed for data storage and retrieval. In the early 1970s integrated circuits also gave rise to microprocessors with functions that can be programmed by software. Both the memory chip and the microprocessor are the essential components of the personal computer which was first developed in the late 1970s.

The rapid technological progress in semiconductor manufacturing has made it possible to increase exponentially the number of transistors that can be placed on a silicon chip. The transistor density has been observed to double every 18 months a phenomenon known as Moore's Law, named after Gordon E. Moore who is a cofounder of Intel Corporation. As, for example, Jorgenson (2001) has reminded us, the first microprocessor in 1971 had 2,300 transistors whereas the Pentium 4 released in November 2000 had 42 million of them. This means that the transistor density has increased on average by 34 per cent per year.

Moore's Law describes the fact that successive generations of semiconductors are better and faster. More data can be stored, retrieved and processed at greater speed. When information is defined as anything that can be digitized encoded as a stream of binary digits or bits this means that a revolution in storing, processing and transmitting information is indeed going on.

Information and communication technology plays a central role here as it develops the required tools. It amplifies brainpower in a way analogous to that in which the previous industrial revolutions amplified muscle power (Cohen, DeLong and Zysman 2000).

Semiconductor prices have plummeted closely parallel to Moore's Law on the growth of chip capacity. Jorgenson (2001) reports that memory chip prices declined by a factor of 27,720 or at 41 per cent per year in the United States between 1974 and 1996. The price decline accelerated to more than 90 per cent per year in the mid-1990s when this industry shifted from a three-year product cycle to a two-year one.

The ongoing technological improvement in semiconductors moves the supply curve of computers down in Figure 2, as illustrated by the shift from S1 to S2. Computer prices fall and quantities purchased rise. If there is no change in the demand curve or if it moves up more slowly than the supply curve shifts down in Figure 2, then the relationship between prices and quantities observed in the market for computers should be a downward-sloping curve.

Unfortunately, data on computer prices and quantities for other countries are not available, preventing direct cross-country comparisons of computer investment or other components of ICT. But in any case, similar price and quantity trends must have materialized elsewhere as well, explaining in part the increasing shares of ICT spending in GDP shown in Figure 1.

Demand-side factors affecting ICT adoption and diffusion are better amenable to international comparison. The level of income is perhaps the most obvious of these factors.

CONCLUSION:

The importance of the question of digital divide lies in the underlying threat that it may get exacerbated as more and more proliferation of the reigning ICT of our time, i.e., the ICTs happen. It does not take a great deal of imagination to see that the patterns of divide coincide with the lines of income inequality. The regional variations also have such a core-periphery status, whereby the regions which are relatively more advanced economically have access to better ICT infrastructure than others. This makes these regions better equipped to reap the benefits of further advances in this field.

Diffusion is supposed to lower these differences and equate the disparities around the world. But, the patterns of diffusion in the presence of income inequalities have shown a picture that has threatening implications for future. The policy framework has to be prepared to face such a scenario.

CHAPTER-IV

THE DETERMINANTS OF DIFFUSION OF ICT: A CROSS COUNTRY ANALYSIS

4.1. Introduction

We will address diffusion of ICTs from the consumption side. Here, we are interested in the diffusion of these technologies (i.e., mobiles, personal computers and internet) as technologies of consumption that end-users acquire and use. This is not the approach taken in most studies, which look at measuring productivity and how it relates to technology adoption and inequality. We will consider ICTs as consumption goods. Hence, looking at how salaries have changed due to the incorporation of new technologies at the workplace and how salaries have changed in order to reward those having the know-how to use them is not our primary goal. Such analyses make more sense when technologies are seen as production goods. In contrast, this study is concerned with finding out the variables that better explain the adoption of consumption ICTs across countries.

In fact, the fundamental hypothesis we intend to test is whether the relationship between economic inequality and technological change can be understood not only on the production side as a complementarity between skills and new technologies[1], but also, from the consumption side, in the way that individuals have disposable income to buy new technology. High levels of inequality may limit the opportunities for new technologies to diffuse: less people have resources available to buy them. If this conjecture is valid, then

[1] As shown in the survey conducted in the Chapter-2

one would expect new technologies to exhibit slower diffusion rates where inequality is higher.

We shall also explore the behaviour of different socio-economic determinants after dividing the countries in terms of their income (GDP per capita) into high income, middle income and low-income countries on the relative rate of growth of diffusion of these technologies. Along the way we shall trace the relationship of older ICTs like cable TV and telephone with the diffusion of the new ICTs considered here, viz., Internet, Personal Computers (PC) and Mobile Phones.

4.2. Model Specification and Methodology:

We divide our analysis into three steps. In the first part the attempt will be to model diffusion of the three ICTs under study here. The next step will be an attempt to link the speeds of diffusion with the measures of income inequality. In the third step we shall try and regress these values of growth of each technology with a host of macro-economic variables.

Step-1

We know that the diffusion of any technology usually follows an S-shaped path[2]. Following the most conventional method, we use a logistic growth curve[3] to model the diffusion of each of these ICTs separately.

---

[2] For a complete survey of the different interpretations of the S-shaped curve of diffusion, see Geroski, P.A., (2000), pp.-603-625.

[3] Pierre-Francois Verhulst developed the logistic growth model for population growth forecasting purposes in 1843. Griliches (1957) was the first to employ it for innovation diffusion. McKnight et al (2001) used this formulation in the context of ICTs.
The model expression is:

The logistic growth curve is defined by

$$y(t) = \frac{y^*}{1 + \exp-(a + bt)},$$

where the specifications and importance of the parameters are according to the Foot Note 3 in this chapter.

After some rearrangement in this model, we get the linear relationship

$$\ln\left(\frac{y^*}{y^* - y(t)}\right) = a + bt \ ,$$

$$y(t) = \frac{y^*}{1 + \exp-(a + bt)} \qquad (1)$$

In Eq. (1), $y(t)$ is the number of adopters at time t. Additionally, Eq. (1) has three parameters: y^*,b and a. parameter y^* measures the number of potential adopters, which is approached by the logistic model after infinite time:

$$\lim y(t) = \lim\left(\frac{y^*}{1 + \exp-(a + bt)}\right) = y^* \qquad (2)$$

Parameter b can be determined as follows. After differentiating and rearranging, Eq. (1) can be transformed into the form:

$$b = \frac{y'(t)/y(t)}{[y^* - y(t)]/y^*} \qquad (3)$$

Now, the numerator of Eq. (3) is the growth rate of the diffusion process. The denominator represents the fraction of potential adopters, into which the innovation has not diffused yet. Parameter b can thus be interpreted as a relative growth rate. It is the growth rate of diffusion divided by the not-yet adopted fraction of potential adopters. Finally, parameter a determines the timing of the diffusion process. It affects the location of the logistic model in the time scale. Together, parameters a and b determine the timing of y'(t)'s maximum:

$$t_{max} = -\left(\frac{a}{b}\right) \qquad (4)$$

Eq. (4) shows that a greater b gives an earlier maximum, since parameter a has a negative sign. This maximum point is also the sales peak of the innovation, the time when most subscribers are gained.

which allows for estimating the parameters of the S-curve directly by ordinary least squares.

The value of y^* is assumed to be 100%, since each of the three technologies considered can, theoretically, be used by each and every person individually in all the countries.

We have fitted an S-shaped curved to the proliferation of each of the three technologies considered for each of the countries used in our analysis. Each S-shaped curve is estimated separately. This procedure generates a rate of growth coefficient for each country for each technology. In other words, the logistic curves serve as a summary device collapsing the levels of penetration of the new technology over time into the rate of growth coefficient. Then, we set up a vector with all these coefficients, $b(c,\tau)$, where c indicates the country and τ the technology.

Step-2

We link diffusion rates to variables designated for income inequality next.

The goal of the second part of our work is to assess the relationship between the rate of growth coefficient, $b(c,\tau)$, and income inequalities across countries.

Consider a single technology and the vector of rate of growth coefficients for that technology $b\tau(c)=b(c,\tau)$. We set up the model

$$b\tau(c)=X(c).\beta\tau+\mu\tau c \qquad \text{(Model-1)}$$

where $X(c)$ is a vector of independent variables used to explain variance in $b\tau(c)$ and $\mu\tau c$ is the error term. As our major goal is to relate the diffusion of technology to inequality, $X(c)$ includes the level of income inequalities for the countries considered. *X(c)* also includes GDP per capita (at constant 1995 US $).

Step-3

Now, we try to relate some other explanatory socio-economic variables with the rate of growth of each technology after dividing the countries in the sample into 3 categories, High Income (HI), Middle Income (MI) and Low Income (LI).

In Model-1 we tried to go for an ordinary least square (OLS) estimation and we averaged out all the explanatory variables, viz., income inequality and GDP over time, in order to cope up with the mass of missing data for different years. But here we go for a generalised least square (GLS)[4] cross-country panel analysis. We do this by generating the *b* values as time varying[5].

---

[4] Panel estimation using GLS[4]:
The basic equation from which the model is developed is given by:
$y_{it} = x_{it} + u_{it}$; where $i = 1.......m$ is the number of units (or panels) and $t = 1.....n$ is the number of observations for the panel *i*. In case of Ordinary Least Squares (OLS), the coefficients are estimated by:

$$\hat{\beta}\ (\text{ols}) = (x'x)^{-1}x'y$$

And the GLS results are given by:

$$\hat{\beta}\ (\text{gls}) = (x'\hat{\Omega}y)^{-1}\, x'\hat{\Omega}^{-1}y,$$

where $\hat{\Omega}$ is the estimated variance-covariance matrix. In many cross-sectional data sets, the variance for each panel generally differs. We suspected heteroscedasticity across the panels. In this chapter, this is confirmed by Cook-Weisberg test for the presence of heteroscedasticity across the panels. This is the reason why, GLS was used instead of the OLS technique.

[5] We take the ceiling value y^* in Eq. (1) in footnote 3 and formed the function, $y(t)^* = \gamma.POPt$, where, POP_t is the population of the country concerned at time *t*, and γ is the fraction of the population which could rationally function as the no. of potential adopters. We started with a value of γ=0.8, i.e., starting with 80% of the people as the potential adopters for all the countries. Although not fully realistic, this model is more realistic than

We set up the model:

$$b_i(\tau,c,t)=\chi^{\tau ct}\beta^{\tau ct}+e^{\tau ct} \qquad \textbf{(Model-2)}$$

where, i= high-income, middle income, low-income.

τ= mobile, internet, personal computer,

c=the countries (we have taken 51 countries in our sample[6])

χ=the vector of explanatory variables to be defined in the next section.

β=the vector of coefficients

e=the error term.

Here $b_i(\tau,c,t)$ captures the speed of diffusion of technology τ, in country c at time t. It is estimated as shown in footnote-5, in this chapter.

4.3. Description of the Explanatory Variables

In the first model, we have regressed two different measures of inequality: "IN", and EHII, standing for the theil index of wage inequality got from UTIP[7], and the estimated household inequalities (EHII) got from the same source[8] respectively, with the b values (speed of diffusion) for all the three technologies separately.

---

assuming that the number of potential adopters remains constant throughout the diffusion period. Now, once $y(t)^*$varies, following the method described in step-1 in this section, we can generate time varying b values for each country in the sample.

[6] To get a list of the countries included in the study here, see Table-4.2 in this chapter.

[7] University of Texas Inequality Project.

[8] Can be accessed at http://utip.gov.utexas.edu/. This database has inequality data up till 1999. But, our period of survey is 1991-2001. Therefore, assuming that the income inequality pattern would not change much in two years' time, we imputed the average inequality values for each country for the missing data.

In the model-2 our quest has been to explain the differential diffusion across the different countries through the explanatory socio-economic factors. For this purpose, we have 14 explanatory variables, which are thought to have an impact on the rate of diffusion of ICTs.

The most obvious variable is the income level captured by GPP per capita (1995 constant US$) denoted by V_1 here. Along with this we have taken a series of other economic factors:

Communications, Computers etc. taken as percentage of service exports (V_2), as also imports of these items (V_3), for we have reason to believe that these have an effect on the rates of adoption of different countries; gross fixed capital formation as percentage of GDP (V_4), ICT expenditure taken as percentage of GDP (V_5), for we have reason to believe that expenditure in ICTs and the capital formation rates should have a positive impact on the rate of growth of ICTs.

We think that ICTs have a leading role to play in the service sector in the economy hence we have taken employment in services as percentage of total employment (V_6). Also the extent of urbanisation as percentage of total population (V_7) is a variable that is almost obvious. We have reason to believe that degree of openness of an economy also influences the availability of these technologies as spillover through trade. For openness (V_{14}) we have taken the ratio of the total of exports and imports to GDP, as the standard proxy.

The human capital has been captured by the levels of secondary education (V_8). To couple with this we have taken the levels of the tertiary school education (V_9), since, we have reason to believe that these technologies are skill-biased to a degree. The number of personal computers installed in education (V_{10}) is taken to supplement this implicit skill-bias hypothesis. To complete the elaborate set of models capturing the quality of extant human capital, we have also included the illiteracy rates (V_{11}).

Finally, an attempt has been made to see whether the adoption of older ICTs like telephone mainlines (V_{12}), and television (V_{13}) have had a positive effect on the rates of adoption of the different countries under study.

The data for all these variables have been taken from World Development Indicators (WDI, 2003). All the values missing in the dataset have been imputed with the group means, for the different income categories.

4.4. Relationship among the diffusion of different ICTs

We start by noting that there is a strong interaction among the evolution of the penetration of the three technologies studied. Also along time, it is possible that one technology exert some influence on the diffusion of another technology that somehow has a connection to the former. We began by performing a bivariate analysis on the penetration of each technology over time that allows for calculating the coefficients of correlation for each pair of technologies. Table 1 depicts the results.

It is worth noting that there is a positive and strong association between the three technologies that we are studying, especially in the case of ownership of personal computers and Internet access. While this might not be surprising because today it is still very likely that one needs a computer to connect to the Internet, the strong association between PCs and mobiles and between mobiles and the Internet shows that technologies in the information revolution are very much tied to each other and the use of one of them clearly prompts the use of the others, especially when the diffusion of newer ICTs that enable to use the internet through cell phones

Table-4.1

Coefficients of Correlation for Pairs of Technologies

ρ(PC-Internet)	0.907
ρ(PC-Mobile)	0.847
ρ(Mobile-Internet)	0.891

The above observation indicates that when examining the diffusion of one technology, one must relate it to the diffusion of the other technologies, for example, because of the, sometimes sine qua non, need of having one technology to use the other. However, we also observe that after a certain critical mass of users has been achieved, the growth of the penetration rate of a technology is self-sustained given the network effects, therefore less dependent on the penetration of complementary technologies. That is, two regimes in the relationship between the diffusion of ICTs and the complementarity among these technologies might be expected.

4.5. Results of Fitting the Logistic Curve

This section discusses the results of fitting S-shaped curves to the proliferation of ICTs, for each technology and for each country, obtained by computing the parameter b of the logistic function by employing the method suggested in section 4.2. Table 4.2. shows the coefficients $b(c,\tau)$ obtained. All the regressors are statistically significant for the three technologies at the 1% level. Additionally, the R^2 for the regressions ran vary between 0.6487 and 0.9971, which are high. Hence, the results confirm the hypothesis that the S-shaped curves are good functional forms to explain the diffusion of ICTs within countries.

If we remember that there is a positive relationship between the rate of growth coefficient b and the proliferation of technology, we can conclude that the technology with a slower diffusion rate is Personal Computers, since b_{PC} is always the lowest coefficient for each country.

It seems convenient to understand why the rate of coefficient growth for personal computers is the smallest of the three rates computed. One potential reason is that the initial investment required to buy a personal computer is substantially superior in comparison to the investment needed for example to use a mobile phone. The technology associated with a PC is older than the others analyzed in this chapter, which implies that the diffusion's stage of PC could be more advanced than for other ICTs. Thus, the growth of mobile and Internet access is higher also because there is a gap to fill until they reach the same diffusion's stage of PCs. Another possible explanation relates to skills. The PC technology is much more skill intensive that the other technologies considered, mobile phones and the Internet. In reality, the skill-demanding characteristic of PC conditions the rate of coefficient growth of the diffusion of such technology.

Finally, it is also possible to observe that at least two thirds of the countries in this sample present a value for parameter b referring to Internet access greater than the respective value for mobile. The remaining countries, with a few exceptions, seem to belong to a group of less developed nations. This would suggest that these countries "leapfrog" to using mobile phones without having used the Internet so much. However, such an analysis must deserve caution. It might be that these countries cannot use so much the

Internet because there is no installed PC based that allows for doing so. To delve more seriously into this issue one should characterize the investments in ICTs in these countries in order to understand to what extent it is easier to deploy wireless technologies and mobile phones rather than computer networks. Other possible explanations for the use of mobile phones as a substitute to fixed phones in less developed societies include the fact that the poor cannot afford installation costs and that fixed lines are not easily available in the market due to infrastructure limitations.

4.6. Analysis of the results of the models

The previous section estimated the growth coefficient for the logistic curves aimed at capturing the diffusion of ICTs in each country. This section relates these coefficients to the macro socio-economic variables discussed in section 4.3, as a way to explain the relationship between these variables and the diffusion of ICTs. Therefore, we have considered a set of models in which we write the growth coefficient as a function of these variables. We divide this section into 2 parts- the first part relating the rate of diffusion to measures of income inequality and the second part with the other variables.

Part-1

The first model includes two independent variables: economic inequality, measured by the Theil Index and represented by IN in our model, and a variable that gauges the ability of the population to acquire additional goods and services - the gross domestic product per capita converted to international dollars using constant 1995 US$ rates:

$$b_T(c) = a_1.IN(c) + a_2.GDP(c) + \varepsilon(c)$$

Equation 1 - Model 1[i]

Table 4.3 shows the results obtained from estimating this model with linear least squares. We observe that inequality has a positive correlation to the rate of growth coefficient and is always significant at the 1% level. Therefore, our study indicates that the diffusion of technology increases with higher levels of inequality. This fact could be explained by the hypothesis of Galbraith (1998) that suggests that that new commodities diffuse from the rich to the masses. In an unequal society, with an economic elite, it would be easier to introduce new technologies, and so one would expect that these new consumer goods become part of the everyday life even for low-income households. As new technologies become mature, their prices fall, and they become available to poorer people at substantially lower prices than were first paid by the economic elites.

As expected, the GDP per capita is positively correlated with the dependent variable and statistically significant at the 1% level for all the three technologies considered. Additionally, note that for this model and for all the three technologies considered, the adjusted R^2 are high (between 0.85 and 0.88) for the whole model, which attests for the explanatory power of this model.

Instead of using the wage inequality Theil index from UTIP, the Model-1[i] includes a variable that measure the household income inequality (EHII). The main difference between the Theil index from UTIP and EHII is that the former pertains only to economic inequality across the industrial sector and the latter is wider in the sense that it includes annual estimates of household income inequality for most countries. The model can be written as:

$$b_T(c) = a_1.EHII(c) + a_2.GDP(c) + \varepsilon(c)$$

Equation-2 -Model-1^{ii}

Looking at **Table 4.4** it is possible to observe that the Eq. (2) model-1^{ii} presents better measures of goodness of fit (adjusted R^2 and F-statistic) when compared with Model 1^{i}. Eq. (2)-model-1^{ii} shows that the variable GDP per capita is not statistically significant for any of the three technologies and that the signs of coefficients for GDP per capita are negative. It is worth remembering that in model 1^{i} this variable is significant at the 1% level. Computing the coefficient of correlation between the two measures of inequality used in the models and the GDP it is possible to see that the results show a low level of association between the variables.

Part-2:

We now go on to the GLS panel study[9] of the different explanatory variables. The results are summarised in **Table-5** and **Table-5a.**

Looking at **Table-4.5,** we can conclude that even though we have used different income levels as control variables (having already divided our samples into 3-income categories), we find continued significance of the variable per capita income (captured by V_1 i.e., the GDP per capita at 1995 constant US $), in all the three income categories and for all the technologies. The results are there in column-1 of **Table-4.4.**

We can see that most of the coefficient here are negative and significant with the exception of mobile and internet for high-income countries and PCs for middle-income countries. This result was also seen in Model 1^{ii}. The

[9] The model is described in detail in **section 4.2.** in this chapter.

explanation can be found in a closer inspection of the diffusion curve. In the S-curve of diffusion of any technology there are two slow growth periods sandwiched in between a high growth period. Though adopters are adopting the ICT still, the rate of growth (speed of diffusion, our dependant variable) is mostly getting slower in high income countries, because, most of them started adopting the ICTs early and are beyond the inflection point of the logistic curve and thus the rate of growth of adoption of these ICTs are moving in the opposite direction to that of increase in income levels in high income countries. But, the case of internet having a positive significant coefficient for high-income countries for GDP per capita is intriguing. One of the explanations that can be given is that adoption of internet is gradually increasing at a faster rate still, due to the fact that it is co-opting other communication technologies, and the access charges are coming down. In the middle-income countries the adoptions of PCs show a positive relationship with the rate of adoption.

Columns 2 and 3 depict the results obtained for the variable V_2 and V_3. They depict the ICT components of service exports and imports respectively. The pattern that emerges is very much according to our expectations. We have reason to believe that Business Process Outsourcing (BPO) has a direction from the developed (high-income) countries to low income countries which will reflect in the positive association of the export variable with the speed of ICT diffusion for the low-income countries but as a negative association for the high-income category of countries. Looking at the results obtained in columns 2 and 3 in Table 4.5.a, we can conclude that our hypothesis has been proved true for high-income countries in case of mobiles and internet, where the coefficient for V_2 are negative and significant but that of V_3 are positive (in the case of mobiles) and significant (in the case of internet). In fact the same trend can also be seen for middle-income countries too for the above said variables, where we find positive association of the speed of diffusion of ICT with the ICT service imports and negative association with ICT exports. This may be because, in our categorisation, we classified the higher middle-income countries of WDI (2003) as our middle-income countries and these countries also outsource their Information Technology Enabled Services (ITES) to the low-income countries. However for Low-income countries, we find the reverse trend for mobile and internet. One anomaly that can be noticed here is the case of PCs. PC is an older ICT and its speed of diffusion is also remarkably slower than the other two considered here. Again the nature of the diffusion curve played a role here in the trends that can be seen. The rates of diffusion of PCs have slowed down in the higher-income countries. Therefore we can see here the positive association of diffusion of PC with the percentage of ICT components in service exports (which has a negative trend over time, i.e. it is coming down over the years for these countries) and a negative association with service imports (which are growing). But for middle-income and low-income countries, where the diffusion of PCs have not been satisfactory, they show a positive association with the percentage of ICT components in service imports (which are coming down for these countries) and a negative association with the service exports.

Gross fixed capital formation (column 4, **Table 4.5.a**) is a proxy for the portion of investment that finally translates into the infrastructure of an economy. We can find a positive association of the variable with the rate of diffusion of all the technologies, underlying the need for a strong infrastructure base for the diffusion of the ICTs. Similarly, for ICT expenditure as percentage of GDP (which is sluggish for the middle income and low-income countries), we can find a positive association with diffusion of PCs, which is the slowest of all the technology to diffuse. This variable has negative coefficients (albeit insignificant) for the rate of growth of mobiles.

The rapid growth of mobiles in the absence of corresponding growth in ICT expenditure is a mystery. Like PCs, internet growth is also positively associated with this variable.

Services (particularly ICT based services) have very low employment elasticity[10]. That is why in most countries we see the employment statistics show a negative relation with the speed of growth. All the relations are statistically significant and have negative sign except PCs for low-income countries, where we see a positive relationship with the proliferation of the technology. This is perhaps alluding to the fact that growing ITES and BPO are actually creating some jobs in these countries.

Table 4.5a, column 7 shows the nature of association of the percentage of population living in urban areas with the speed of diffusion of the three ICTs. We can see that the rates of diffusion are mostly negatively related with this variable for low-income and middle-income countries (with the only exception being PCs in case of low-income countries). But, for high-income countries, not unexpectedly, the association is positive and significant for two out of three ICTs (mobile, internet). This is due to the fact that unlike low-income and middle-income countries, the urban-rural divide is not that rigid in the high-income countries. In case of PCs for low-income countries, the positive and significant association could be because of the sluggish rate of growth of PCs.

The first four columns of Table 4.5.a show the skill capability of human capital and its relationship in the panel study with the rate of diffusion of these ICTs. We can see that, both primary and tertiary education (variable 8

[10] i.e., they do not show significant changes in employment creation even with creation of new jobs.

and 9) are positively associated with the rate of diffusion of all the three technologies, wherever they are significant. Variable (10) captures an advanced skill (viz., computers in education). Except mobiles for middle-income countries, it has a positive relationship with the rate of diffusion of internet in high-income countries and that of PCs in middle-income and low-income countries as expected. The fact that for mobiles this variable is significantly negative in all countries is a puzzle. The column 11 in Table 5.a shows the relationship of illiteracy rates with the speed of diffusion. In case of internets and mobiles, we can find the expected negative and significant relationship with illiteracy rates of different countries. But, the positive and significant association between illiteracy rates and the rate of diffusion of PCs in the regression (though contrary to our analysis) can be attributed to the on-to-one relationship between the illiteracy rates and the growth of PCs.

Next, we see the relationship between the older ICTs- telephone mainlines (column 12) and television (column 13) and the three ICTs we are studying here. We can see the substitution effect of the mobiles for telephone mainlines in the negative and significant association between these two (for the low-income and middle-income countries). The negative association between the telephone mainlines and PCs is more difficult to explain. The same technology substitution effect can be seen in the negative association between televisions and PCs for all the three categories of countries. In the case of high-income countries the rate of growth of television has come down, and thus it has a negative and significant relationship between television and mobiles here. But, in low-income countries television is still growing and thus it has a positive and significant coefficient for this category (i.e., vis-à-vis mobiles).

The last column in the table captures the relationship of the rate of diffusion with the degree of openness of an economy (proxied by the ratio of the sum of exports and imports and GDP). We can see that the degree of openness of an economy has had a positive spill over effect over the diffusion of the ICTs. The only exception here is the case of diffusion of PCs in low-income countries. We see from the adoption figures that in spite of the gradual opening of the economies, the diffusion of PCs has not spread as it did in the high-income and middle-income countries.

The explanatory power of model-2 can be attested through the fact that for all the models used in this part, the Wald Chi-square statistics is significant at 1% level of significance.

4.7. Conclusion:

We found many significant aspects of diffusion of ICTs in this chapter. For a start, it proved negative our hypothesis that diffusion of ICTs diffuse faster in the presence of more equality. In fact, we saw the positive association of income inequalities with the rate of diffusion of the three ICTs studied here. This bares a very uncomfortable fact and that is- most of the ICT revolution that we are talking about is actually affecting a microscopic portion of the people. This is not to play down the importance of this as a GPT-we can not just shy away from it. But, like we saw in the survey in Chapter-2 in this study, where we found that ICTs through its inherent skill-bias, it actually pushes up the wage inequalities in an economy, this chapter also showed the unmistakable fact that though there is considerable diffusion of the ICTs, it has strong complementarities with skill (education here) and it is urban based mostly.

Yet again we confirmed some oft-found conclusions about ICTs- that it has a significant skill-bias, i.e., most of its adopters need some educational qualification to adopt it, even when it is considered from a consumption perspective. We proved (albeit indirectly) the fact that its diffusion is affected by the shifts in the international labour market, where through BPO high income nations are sending out their low-end jobs to low-income countries. But, a lot of limitations in this study stem from the nature of the data we have taken. WDI (2003), though a repository of a great number of variables, has many gaps. Though every effort was made to maintain the robustness of the analysis, some data imputing (by group averages) had to be made, which smoothened out the time variations in the study. The model specification also, we think suffers from the defect of being dictated by the availability of data.

Significantly though, the goal of our study, i.e., analysing the causal factors of differential diffusion of ICTs in the presence of income inequalities showed that Kuznets' hypothesis may be at work in this diffusion process.

Table-4.2

Country	inc_code	b_pc	b_internet	b_mobile
Argentina	2	0.23	0.75	0.76
Australia	1	0.16	0.44	0.6
Austria	1	0.19	0.5	0.42
Belgium	1	0.2	0.8	0.5
Brazil	2	0.3	0.82	1.1
Bulgaria	3	0.14	1.2	1
Canada	1	0.18	0.6	0.4
Chile	2	0.24	0.7	0.5
China	3	0.23	0.8	0.81
Colombia	3	0.22	0.56	0.6
Croatia	2	0.21	0.71	0.72
Cyprus	1	0.34	0.91	0.54
Czech Republic	2	0.3	0.41	1
Denmark	1	0.21	0.7	0.3
Ecuador	3	0.3	0.6	0.6
Egypt, Arab Rep.	3	0.25	0.9	0.33
Finland	1	0.21	0.5	0.34
France	1	0.16	0.6	0.5
Germany	1	0.2	0.6	0.6
Greece	1	0.1	0.6	0.8
Hong Kong, China	1	0.2	0.6	0.5
Hungary	2	0.23	0.81	0.75
Iceland	1	0.28	0.6	0.32
India	3	0.15	0.7	0.75
Ireland	1	0.18	0.71	0.6
Israel	1	0.16	0.64	0.7
Italy	1	0.18	0.74	0.67
Japan	1	0.2	0.82	0.55
Korea, Rep.	2	0.25	0.76	0.66
Kuwait	1	0.28	0.7	0.31
Latvia	2	0.21	0.72	0.76
Lithuania	2	0.17	0.75	0.76
Luxembourg	1	0.03	0.8	0.61
Malaysia	2	0.27	1.3	0.44
Mexico	2	0.21	0.73	0.6
Netherlands	1	0.2	0.46	0.47
New Zealand	1	0.2	0.7	0.5
Norway	1	0.2	0.5	0.3
Pakistan	3	0.14	0.71	0.64
Philippines	3	0.2	1	0.5
Poland	2	0.24	0.8	1.03
Russian Federation	3	0.3	1	0.9
Singapore	1	0.26	0.7	0.4
Slovak Republic	2	0.3	0.8	1.03
South Africa	2	0.26	0.55	0.8
Spain	1	0.18	0.71	0.76
Sweden	1	0.21	0.56	0.34
Thailand	3	0.23	1.33	1.54
Turkey	2	0.22	0.86	0.63
United Kingdom	1	0.14	0.65	0.41
United States	1	0.13	0.42	0.4

*Here income codes 1,2,3 denote high, middle and low income countries according to WDI(2003)

Table-4.3

	Model-1[i]		
	PC	Internet	Mobile
IN	2.823**	10.589**	9.024**
	(8.80)	(10.05)	(8.97)
GDP Per Capita	7.9e-06**	0.000021**	0.000017**
	(7.83)	(6.58)	(5.69)
Adjusted R^2	0.878	0.880	0.849

[t-test values in parentheses
* Significant at 5%; ** significant at 1%; the variables are as described in section 4.3, in this chapter.]

Table-4.4

	Model-1[ii]		
	PC	Internet	Mobile
EHII	0.0062**	.0213**	.0177**
	(12.30)	(12.64)	(8.97)
GDP Per Capita	-9.6e-07	-5.05e-06	-3.86e-06
	(0.76)	(-1.20)	(-0.90)
Adjusted R^2	0.914	0.914	0.873

[t-test values in parentheses
* Significant at 5%; ** significant at 1%; the variables are as described in section 4.3, in this chapter.]

Table-4.5
(Regression Results for Model-2)

Category	v1	v2	v3	v4	v5	V6	V7
Mobile							
HI	-2.50E-06 *	-0.02 **	0.004 **	-.002	-.008	-0.021 **	0.002 *
	(2.07)	(4.01)	(5.49	(1.21)	(1.63	(3.08)	(2.54)
MI	-1.34E-06	-0.005 **	0.003 **	0.004	-.005	-0.004 *	-0.002 *
	(0.08)	(3.57)	(2.59	(1.96)	(0.69	(2.34)	(1.97)
LI	-4.90E-06 **	-.00017	-0.002 *	0.008 **	-.003	-0.003 **	-0.004 **
	(3.09)	(0.26)	(2.37	(4.93)	(0.51	(3)	(6.75)
Internet							
HI	3.68E-06 **	-0.002 **	-.0001	-0.01 **	0.003	-.002	0.001 *
	(2.99)	(3.59)	(1.79	(5.65)	(0.60	(1.42)	(2.27)
MI	-0.00002 *	0.003 **	.001	0.004 *	0.031 **	0.005 **	-0.006 **
	(2.08)	(3.2)	(1.33	(2.41)	(4.91	(3.31)	(6.52)
LI	-.002 **	.001	-0.002 **	-.002	0.029 **	-0.005 **	-0.002 **
	(3.58)	(1.67)	(3.58	(1.17)	(6.67	(5.5)	(4.06)
PC							
HI	-3.11E-06 **	-.0004	-0.001 **	0.003 **	-.001	-.001	.0001
	(4.69)	(1.52)	(2.85	(3.22)	(0.43	(1.14)	(0.30)
MI	7.94E-06 **	-0.001 **	0.001 **	0.001	0.005 **	-.0001	-.0001
	(3.14)	(2.72)	(3.82	(1.80)	(3.79	(0.51)	(0.70)
LI	-3.83E-06 **	-.0002	0.0004 *	0.003 **	.0002	0.001 *	0.001 **
	(9.04)	(1.31)	(2.38	(7.96)	(0.22	(1.96)	(6.41)

[Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%; the variables are as described in section 4.3, in this chapter.]

Table-4.5.a
(Regression Results for Model-2)

Category	V8	V9	V10	V11	V12	V13	V14
Mobile							
HI	.0003	0.001 **	-2.01e-08	-0.029 **	-.0001	-0.0002 **	0.002
	(0.91)	(2.88)	(1.23)	(12.57)	(1.97)	(3.76)	(0.54)
MI	0.003 **	0.002	-1.90E-07 **	0.008 **	-0.001 **	.0001	0.021 **
	(2.82)	(1.60)	(2.64)	(3.07)	(5.65)	(0.83)	(4.87)
LI	.0004	0.002 *	-2.82e-08	-0.009 **	-0.00036 **	0.0002 *	0.004
	(0.85)	92.57)	(1.05)	(9.19)	(3.82)	(2.57)	(1.12)
Internet							
HI	.0003	0.001 **	5.75E-08 **	-0.007 **	-0.00003	-.0001	0.002
	(1.13)	(2.77)	(3.48)	(2.89)	(0.39)	(1.64)	(0.70)
MI	0.002 **	0.001	5.24e-08	-0.014 **	.00002	-.0001	0.009 *
	(2.58)	(1.21)	(0.89)	(6.38)	(0.14)	1.54)	(2.48)
LI	.00004	0.001 *	-2.52e-08	-0.003 **	-.00003	.00007	-.003
	(0.10)	(2.25)	(1.11)	(3.9)	(0.34)	(1.06)	(1.12)
PC							
HI	.0003	0.0003	-6.73e-11	0.006 **	.00004	-0.0002 **	-.003
	(1.73)	(1.20)	(0.01)	(4.44)	(0.82)	(6.68)	(1.61)
MI	0.0003 *	.00009	4.74E-08 **	0.003 **	-0.0002 **	0.00005 **	0.002 *
	(2.31)	(0.58)	(4.12)	(6.6)	(8.19)	(2.84)	(2.5)
LI	0.0003 **	0.001 **	1.70E-08 *	.0001	-.00004	-0.0001 **	-0.002 *
	(2.68)	(4.02)	(2.38)	(0.68)	(1.71)	(5.14)	(2.26)

[Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%; the variables are as described in section 4.3, in this chapter.]

CHAPTER-5

CONCLUSION

We have established the causal link between income inequalities extant both within and among the different countries in the world on the one hand, and the nature of diffusion of ICTs on the other hand. If we take a look into the nature of different GPTs in the past and their patterns of diffusion, we will find some very consistent patterns emerging all through. Whichever place the GPTs may originate, diffusion through imitation activities has been a mode of dispersal of the technologies to other societies and the means to catch up with the leader/frontier, which almost always happens to be the pioneer. There are two aspects to the causal linkages between the GPTs and their linkages with the inequality pattern of the world.

We have a Schumpeterian perspective all the time when we talk of growth and this neo-technology perspective stresses upon the fact that it is technological innovations, which sustain growth. However diffusion is a short-cut from the constant need to innovate, but at the same time sustain a healthy growth rate. On a mezzo-scale one can see that diffusion ameliorates the differences in technological endowment and fosters a faster growth rate. The case of successful catch-up of countries lagging behind by successfully imitating and integrating the diffusion the new GPT with their socio-economic set-up has been historically proven. But, the catch here is successful adaptation of the GPT to the socio-economic institutions of the country. Since, diffusion of any GPT actually creates newer patterns of skill-endowment divide and hence queers the extant income inequalities.

There are two aspects to the debate over the skill-biased technological change (SBTC) hypothesis. While some are of the view that the skill-bias is particular to certain technologies which are inherently so; whereas most of the technologies by its nature require skill-in-use and hence the skill-bias. Whatever is the case, one needs to look into the fact that Acemoglu (2001) argued to account for the relative absence of wage-difference induces income inequality in the western European countries. He showed that the countries in Europe have not showed appreciable increase in the income inequality rates because of the labour laws and strong unionisation there making it a self-regulating mechanism as a guard against drastic shifts in wage gradients. Therefore, in low-income countries the onus is on the neo-liberal regimes not to go for a blind imitation of the Bretton Wood institutes in making stringent exit laws should take a leaf from this evidence.

The fact is that, while many countries have benefited from the information and communication technology revolution as producers, as yet there are not many countries in which this technology has had visible impacts on productivity and economic growth at the aggregate level. In the long run, however, the benefits from ICT use are likely to exceed the benefits from its production. Moreover, whereas it is not possible for all countries to become ICT producers, it is certainly feasible for them to become its sophisticated users. This alternative is becoming even more attractive over time than the first option because of the continuing fast progress in ICT technology and the concomitant rapid decline of its price. While the adoption of ICT may not be sufficient to obtain the benefits from its use, it is definitely necessary. Policy-makers' attention should thus be drawn to the determinants of adoption and diffusion.

It was shown that the level of income is a major determinant of ICT use. There is not much, however, that decision-makers can directly do to narrow down the GDP gap. The same conclusion applies to the production structure of the economy. The other determinants of ICT adoption and diffusion are better suitable to policy-making. The empirical analysis performed in this study as well as the results of many other studies show that the relative price of ICT matters for its adoption. If prices can be reduced by lowering taxes, tariffs and other trade barriers on ICT imports or by increasing competition in telecommunications markets, then these are the appropriate policy measures for promoting higher use.

Education matters as well. Its impact turned out to be very strong in the empirical analysis conducted here. Better educated workers have a comparative advantage with respect to learning and implementing new technology. Also, ICT technologies and their applications, such as business information systems, have been developed in advanced countries and, therefore, tend to be skill-complementary by design. But, given that ICT enables the redesign of production, work and management practices in any organization, an investment in the mere training of technical skills is not likely to be sufficient to promote the adoption and diffusion of ICT. The upgrading of behavioural and interpersonal skills is at least equally important.

Training and education are important not only in providing skills for work and production, but also for providing a sufficiently strong demand base for digital or 'knowledge' products. As argued in the introductory section of this study, unlike physical goods, digital goods are non-rival in the sense that their use by one person, firm or country does not prevent others from using them. Once invented, they can be copied and transferred at negligible costs. For such products, it is the demand rather than the supply that limits adoption and diffusion. Consequently, training and educating consumers to become sophisticated users of ICT will encourage their participation in the information economy and promote the use of ICT.

There seems to be the need to rethink a lot of things while implementing the decisions for a rapid diffusion of ICTs.

BIBLIOGRAPHY

Acemoglu, D. (2002a). "Technical Change, Inequality and the Labour Market,", *Journal of Economic Literature*, 40: 7-72.

Acemoglu, D. (2002b). "Cross-country Inequality Trends," *Economic Journal*, 113 (485): F121-F149.

Acemoglu, D., and Pieshcke, J. S. (2000). "Certification of Training and Training Outcomes,", *European Economic Review*, 44: 917-927.

Acemoglu, D., and Zilibotti, F. (2001). "Information Accumulation in Development,", *Journal of Economic Growth*, 4: 5-38.

Acemoglu, Daron (1999a) "Changes in Unemployment and Wage Inequality: An Alternative Theory and Some Evidence" *American Economic Review*, 89, 1259-1278.

Acemoglu, Daron and Jörn-Stefen Pischke(1999) "The Structure of Wages an Investment in General Training" *Journal of Political Economy*, 107, 539-572.

Acemoglu, Daron, (1996) "A Microfoundation for Social Increasing Returns in Human Capital," *Quarterly Journal of Economics*, 111, 779-804.

Acemoglu, Daron, (1999) "Patterns of Skill Premia", *NBER Working Pa*per No. 7018.

Acemoglu, Daron, (2000), "Technical Change, Inequality, and the Labour Market, *NBER Working Paper* No. 7800.

Acemoglu, Daron, Phillipe Aghion and Gianluca Violante, (2000) "Technical Change, Deunionization and Inequality, *MIT mimeo.*

Aghion, P., and Williamson, J. G. (1998). *Growth, Inequality and Globalization.* Cambridge; Cambridge University Press.

Aghion, P., Caroli, E., and Peñalosa, C. G. (1999). "Inequality and Economic Growth: The Perspective of the New Growth Theories," *Journal of Economic Literature,* 37: 1615-1660.

Aghion, P., P. Howitt. (1992) A Model of growth through creative destruction. *Econometrica.*60: 323-51

Aghion, Philippe and Peter Howitt (1998), *Endogenous Growth Theory,* Cambridge, MA, MIT Press.

Aghion, Philippe, (2000), "Technical Change, Institutions, and the Dynamics of Inequality" *NBER Working Paper,* No. 7713.

Aghion, Philippe, Peter Howitt, and Gianluca Violante, (2000) "Technology, Knowledge, and Inequality" *NBER Working paper.*

Ahmad, Syed, (1966). "On The Theory of Induced Invention," *Economic Journal* LXXVI, pp. 344-357.

Atkinson, A. B. (1997). "Bringing Income Distribution in from the Cold," *The Economic Journal,* 107: 291-321.

Autor, D. H., Katz, L. F., and Krueger A. B. (1998). "Computing Inequality: Have Computers Changed the Labour Market," *Quarterly Journal of Economics,* 113: 1169-1213.

Autor, David and Frank Levy and Richard Murnane, (2000), "Upstairs, Downstairs: Computer-Skill Complementarity and Computer-Labour Substitution on Two Floors of a Large Bank, *NBER Working Paper 7890.*

Autor, David and Lawrence Katz and Alan Krueger, (1998), "Computing inequality: Have Computers Changed the Labour Market?" *Quarterly Journal of Economics,* (CXIII), November, pp. 1169-1214.

Autor, David, Alan Krueger and Lawrence Katz, (1998) "Computing Inequality: Have Computers Changed the Labour Market?" *Quarterly Journal of Economics,* CXIII, 1169-1214.

Autor, David, Frank Levy and Richard Murnane (2000) "Computer Cognition and Human Cognition: The Skill Content of Recent Technological Change" *MIT mimeo.*

Bailey, Martin and Robert Gordon (1988) "The Productivity Slowdown: Measurement Issues and Explosion of Computer Power" *Brookings Papers on Economic Activity, macroeconomics,* volume 2, 379-431.

Bairoch, Paul (1988), *Cities and Economic Development: from the Dawn of History to the Present,* University of Chicago Press, Chicago, translated by Christopher Braider.

Barro, R. J. and J.-W. Lee (2001). International data on educational attainment: Updates and implications. *Oxford Economic Papers* 53: 541-63.

Bartel, Ann P. and Frank Lichtenberg, (1987) "The Comparative Advantage of Educated Workers in Implementing New Technology," *Review of Economics and Statistics,* 49, 1-11.

Bartel, Ann. and Nachum Sicherman, (1998) "Technological Change and the Skill Acquisition of Young Workers," *Journal of Labour Economics* 16, 718-755.

Beaudry, Paul and David, Green (1999) "What is Driving US and Canadian Wages: Exogenous Technical Change or Endogenous Choice of Technique?" *NBER Working Paper.*

Beilock, R., and Dimitrova, D. V. (2003). "An Exploratory Model of Inter-country Internet Diffusion," *Telecommunications Policy*, 27: 237-252.

Berman, Eli and John Bound and Stephen Machin, (1998), "Implications of Skill- Biased Technological Change: International Evidence," *Quarterly Journal of Economics*, CXIII, 1245-1280.

Berman, Eli and John Bound and Zvi Griliches, (1994), "Changes in the Demand for Skilled Labour within U.S. Manufacturing: Evidence from the Annual Survey of Manufacturers," *Quarterly Journal of Economics* (CIX), May, pp 367-397.

Berman, Eli, and Stephen Machin, (2000) "SBTC Happens! Evidence on the Factor Bias of Technological Change in Developing and Developed Countries", *MIT mimeo.*

Berman, Eli, John Bound and Stephen Machin(1998) "Implications of Skill-Biased Technological Change: International Evidence," *Quarterly Journal of Economics*, CXIII, 1245-1280.

Berman, Eli, John Bound and Zvi Griliches, (1994) "Changes in the Demand for Skilled Labour within U. S. Manufacturing Industries: Evidence from the Annual Survey of Manufactures," *Quarterly Journal of Economics*, 109, 367-365.

Blackburn, David Bloom and Richard Freeman (1992) "Changes in Earnings Differentials in the 1980s: Concordance, Convergence, Causes, and Consequences" *NBER Working Paper.*

Blau, Francine D. and Lawrence M. Kahn (1996) "International differences in male wage inequality: Institutions versus market forces," *Journal Political Economy* 104, 791-837.

Borghans, L. A., and ter Weel, B. (2002). "The Diffusion of Computers and the Distribution of Wages," *ROA working paper series number 3.*

Borjas, George J. and Valerie Ramey, (1995) "Foreign Competition, Market Power and Wage Inequality," *Quarterly Journal of Economics,* 110, 1075-1110.

Borjas, George J., Richard B. Freeman, and Lawrence F. Katz, (1997) "How much do Immigration and Trade Affect Labour Market Outcomes?," *Brookings Papers on Economic Activity,* 1, 1-90.

Boskin Michael et al(1998) "Consumer Prices, The Consumer Price Index, and The Cost of Living," *Journal of Ec. Perspectives* vol. 12, , 3-26.

Bound, J, and Johnson, G. (1992). "Changes in the Structure of Wages in the 1980s - An Evaluation of Alternative Explanations," *American Economic Review,* 82: 371-392.

Bound, John and George Johnson (1992) "Changes in the Structure of Wages in the 1980s: An Evaluation of Alternative Explanations" *American Economic Review,* June, 82 (3), pp 371-92.

Bound, John and George Johnson, (1992), "Changes in the Structure of Wages in the 1980's: An Evaluation of Alternative Explanations," *American Economic Review (82)*, June, pp. 371-392.

Braverman, Harry, (1974), *Labour and Monopoly Capital: The Degradation of Work in the Twentieth Century*, Monthly Review Press, New York.

Brendt, Ernie, Catherine Morrison and Larry Rosenblum (1994) "High-tech Capital Formation and Labour Composition in U.S. Manufacturing Industries: An Exploratory Analysis" *Journal of Econometrics*, volume 65, 9-43.

Breshnahan, T.F., and Trajtenberg, M. (1995). *General Purpose technologies:* "Engines of Growth?", *Journal of Econometrics* 65: 83-108

Bresnahan, Timothy F., (1999) "Computerization and Wage Dispersion: An Analytical Reinterpretation," *Stanford University Mimeo.*

Bresnahan, Timothy F., Erik Brynjolfsson, and Lorin M. Hitt, (1999) "Information Technology, Workplace Organization and the Demand for Skilled Labour: Firm-level Evidence," *NBER Working Paper* 7136.

Bresnahan, Timothy, (1999), "Computerisation and Wage Dispersion," *Economic Journal* (109), June, pp. F390-F415.

Card, D. and Lemieux, T. (2000). "Can Falling Supply Explain the Rising Return to College for Younger Men? A Cohort-based Analysis," *Quarterly Journal of Economics*, 116: 705-746.

Card, David and Thomas Lemieux, (1999) "Can Falling Supply Explain the Rising Return to College for Younger Men?," *University of California, Berkeley Mimeo.*

Card, David E. and Alan Krueger, (1992) "School Quality and Black-White Relative Earnings: A Direct Assessment," *Quarterly Journal of Economics* 107, 151-200.

Card, David, Francis Kramartz and Thomas Lemieux (1996);"Changes in the Relative Structure of Wages and Employment: A Comparison of the United States, Canada and France" *Mimeo.*

Caroli, Eve and John van Reenen, (1999) "Wage Inequality and Organizational Change", *UCL mimeo.*

Caselli, Francesco(1999). "Technological Revolutions" *American Economic Review.* Vol. 89, No-1.

Caselli, F. and W.J. Coleman II (2001), Cross-country technology diffusion: The Case of Computers, *American Economic Review: Papers and Proceedings* 91: 328-335.

Castells, M. (1996). *The Rise of the Network Society, The Information Age: Economy, Society and Culture,* Vol. I. Oxford; Blackwell Publishers Ltd.

Cohen, S., B. DeLong and J. Zysman (2000). Tools for thought: What is new and different about the "e-conomy". *University of California, Berkeley. Mimeo.*

Cohen, Sarit and Chang-Tai Hsieh, (2000) "Macroeconomic and Labour Market Impact of Russian Immigration in Israel", *Princeton University mimeo.*

Cowell, F. A. (1999) "Measurement of Inequality," in Atkinson, A. B. and Bourguignon F. (eds) *Handbook of Income Distribution*, North Holland, Amsterdam.

David, P. (1991), Computer and Dynamo: The modern productivity paradox in a not too distant future. In *Technology and Productivity: The Challenge for Economic Policy*. Paris. OECD.

David, Paul, (1990) "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox" *American Economic Review*. Vol. 80 (2), 355-61.

Davis, Steven J., John Haltiwanger, and Scott Schuh, (1996) *Job Creation and Destruction* MIT Press, Cambridge.

Davis, Steven J.; (1992) "Cross-Country Patterns of Changes in Relative Wages" *NBER Macroeconomic Annual*, MIT Press, Cambridge, 239-292.

Devroye, Dan and Richard Freeman, (2000) "Does Inequality in Skills Explain Inequality of Earnings across Countries?" *Harvard University mimeo.*

DiNardo, J., and Pischke, J. S. (1997). "The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure too?," *The Quarterly Journal of Economics*, 112: 291-303.

DiNardo, J., and Pischke, J.S., (1997) " The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure too?" *The Quarterly Journal of Economics*, 112: 292-303

DiNardo, John, Nicole Fortin and Thomas Lemieux (1995) "Labour market institutions, and the distribution of wages, 1973-1992: A semiparametric approach," *Econometrica* 64, 1001-1044.

Dixon, R. (1980). "Hybrid Corn Revisited," *Econometrica*, 48: 1451-1461

Du Boff, R. B. (1967). The introduction of electric power in American manufacturing. *Economic History Review* 20: 509-518.

Dudley, L. (1998). Communications and Economic Growth, *European Economic Review.*

Easterly, W. (2002). "Inequality does Causes Underdevelopment: New evidence from commodity endowments, middle class share, and other determinants of per capita income," *Center for Global Development working paper number 1.*

Fagerberg, Jan (Sep., 1994), Technology and International Differences in Growth Rates, *Journal of Economic Literature*, Vol. 32, No. 3., pp. 1147-1175.

Foster, Andrew and Mark Rosenzweig(1996) "Technical Change in Human Capital Return and Investments:Evidence from the Green Revolution" *American Economic Review*, 86, , 931-953.

Frank, Robert H. and Phillip J. Cook, (1995) *The Winner-Take-All Society*, Free Press, New York.

Freeman Richard and Edward Lazear (1995) "An Economic Analysis of Works Councils" in Rogers,Joel and Streeck,Wolfgang, eds. *Works councils: Consultation, representation, and cooperation in industrial relations.* National Bureau of Economic Research

Comparative Labour Markets Series. Chicago and London: University of Chicago Press, (1995), pages 27-50.

Freeman, Richard and Karen Needles, (1993) "Skill Differences in Canada in an Era of Rising Labour Market Inequality," in D. Card and R. Freeman, eds., *Small Differences That Matter*, University of Chicago Press and NBER, Chicago, IL.

Freeman, Richard B. (1975), "Overinvestment in College Training?," *Journal of Human Resources*, 10, 287-311.

Freeman, Richard(1986) "Demand For Education" Chapter 6 in Orley Ashenfelter and Richard Layard (editors), *Handbook of Labour Economics*, North Holland, Vol I, 357-386.

Freeman, Richard, (1991) "How Much Has De-unionization Contributed to the Rise of Male Earnings Inequality?" *NBER working paper 3826.*

Friedberg, Rachel, (1997) "The Impact of Mass Migration on the Israeli Labour Market," *Brown University Population Studies and Training Centre Working Paper 97-11..*

Galbraith, J. K. (1998). *Create Unequal: The Crisis in American Pay.* New York, The Free Press.

Galbraith, J. K., and Kum, H. (2003). "Estimating the Inequality of Household Incomes: Filling Gaps and Correcting Errors in Deininger & Squire," *UTIP working paper number 22.*

Galor Oded and Daniel Tsiddon, (2000), "Technological Progress, Mobility and Economic Growth" *American Economic Review*, LXXXVII, pp 363-382.

Galor, Oded and Omer Maov (2000) "Ability Biased Technological Transition, Wage Inequality and Economic Growth" *Quarterly Journal of Economics,* 115.

Gandal, Neil and Gordon H. Hanson, and Matthew J.Slaughter, (2000) "Technology, Trade, and Adjustment to Immigration in Israel," *Dartmouth College mimeo.*

Gebreab, F. A. (2002). "Getting Connected: Competition and Diffusion in African Mobile Communications Markets," *World Bank Policy Research working paper number 2863.*

Geroski,P.A.,(2000) "Models of Technology Diffusion", *Research Policy* 29 , 603-625.

Goldin, Claudia and Lawrence F. Katz, (1998) "The Origins of Technology-Skill Complementarity," *Quarterly Journal of Economics,* 113, 693-732.

Goldin, Claudia and Lawrence Katz, (1995). "The Decline of Non-Competing Groups: Changes in the Premium to Education, 1890 to 1940", *NBER W.P. No. 5202.*

Goldin, Claudia and Lawrence Katz, (2000). "Education and Income in the Early 20th-century: Evidence from the Prairies", *Journal of Economic History.* 60 (September), 782-818.

Goldin, Claudia and Robert Margo, (1992) "The Great Compression: The Wage Structure in the United States at Mid-Century," *Quarterly Journal of Economics,* 107, 1-34.

Gordon, Robert (1990), *Measurement of Durable Goods Prices,* University of Chicago Press.

Gordon, Robert (1998), "Current Productivity Puzzles from a Long-term Perspective" *North-western University mimeo.*

Gosling, Amanda, (1998) "The Determination of Union Status and Wages in British Establishments", *Discussion paper 491, University of Essex.*

Gottschalk, Peter and Robert Mofitt, (1994) "The Growth of Earnings Instability in the U. S. Labour Market," *Brookings Papers on Economic Activity* 2, 217-272.

Gottschalk, Peter and Timothy M. Smeeding, (1997) "Cross-National Comparisons of Earnings and Income Inequality," *Journal of Economic Literature*, 35, 633-687.

Gould, Eric D., Omer Moav, and Bruce A. Weinberg, (2000) "Precautionary Demand for Education, Inequality, and Technological Progress," *MIT mimeo.*

Green, Constance M., Eli Whitney and Little, Brown (1956) *The Birth of American Technology*, Boston.

Greenwood, J. (1997), *The Third Industrial Revolution: Technology, Productivity, and Income Inequality*. Washington: AEI Press.

Greenwood, Jeremy , Zvi Hecowtiz and Per Krusell, (1997) "Long-Run Implications of Investment-Specific Techological Change," *American Economic Review*, vol. 87 [3], 342-362.

Greenwood, Jeremy and Mehmet Yorukoglu, (1997), *"1974" Carnegie-Rochester Conference Series on Public Policy*, XLVI, 49-95.

Griliches, Z. (1957). "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrica*, 25: 501-522.

Griliches, Zvi, (1969) "Capital-Skill Complementarity," *Review of Economics and Statistics 51*, 465-468.

Grout, Paul, (1984) "Investment and Wages in the Absence of Binding Contracts: A Nash Bargaining Approach," *Econometrica*, 52, 449–460.

Habakkuk, H.J., (1962), *American and British Technology in the Nineteenth Century*, London: Cambridge University Press.

Hall, B. H., and Khan, B. (2003). "Adoption of New Technology," Draft of an article for publication in Jones, Derek C., *Handbook of Economics in the Electronic Age*, Academic Press.

Hanson, Gordon H. and Ann Harrison (1994), "Trade Technology, and Wage Inequality: Evidence from Mexico," (September), *MIT mimeo.*

Hargittai, E. (1999). "Weaving the Western Web: Explaining Differences in Internet Connectivity among OECD Countries," *Telecommunications Policy*, 23: 701-718.

Haskel, Jonathan E. and Slaughter, Matthew J., (2001)"Trade, Technology, and U.K. Wage Inequality," *The Economic Journal*, 111, January, pp. 163-187

Haskel, Jonathan E. and Slaughter, Matthew J., (2002)"Does the Sector Bias of Skill-Biased Technological Change Explain Changing Skill Premia?", *European Economic Review*, 46 (10), December, pp. 1757-1783.

Hayami, Yujiro and Vernon Ruttan (1970), "Factor Prices and Technical Change in Agricultural Development: the U.S. and Japan, 1880-1960" *Journal of Political Economy*, LXXII, 1115-1141.

Helpman, E. Ed. (1998), *General Purpose Technology and economic growth*, The MIT Press, Massachusetts, US.

Hornstein, Andres and Per Krusell (1996), "Can Technology Improvements Cause Productivity Slowdowns?," *NBER Macroeconomic Annual*, vol. 11, pp. 209-259.

IMF (2002). *World Economic Outlook Database.*

ITU (2002). *World Telecommunication Indicators 2002.* CD-Rom. International Telecommunication Union, Geneva.

James, John A., and Jonathan S. Skinner, (1985) "The Resolution of the Labour-Scarcity Paradox," *Journal of Economic History*, Volume 45, pp.513 - 540.

Jerome, Harry, (1984), *Mechanization in History*, National Bureau of Economic Research, New York.

Johnson, George (1997) "Changes in Earnings Inequality: The Role of Demand Shifts" *Journal of Economic Perspectives*, 11, 41-54.

Jorgensen, Dale, W. and Kevin J. Stiroh (2000), "Raising the Speed Limit: U.S. Economic Growth in the Information Age" in the *Brookings Papers on Economic Activity.*

Juhn, Chinhui, Kevin M. Murphy and Brooks Pierce (1993);"Wage Inequality and the Rise in Returns to Skill" *Journal of Political Economy* ,Vol. 101, pp 410-442.

Katz, Lawrence and Kevin Murphy(1992), "Changes in Relative Wages: Supply and Demand Factors" *Quarterly Journal of Economics*, CVII, 35-78.

Katz, Lawrence, and David Autor, (1999)"Changes in the Wage Structure and Earnings Inequality" in O. Ashenfelter and D. Card, eds., *The Handbook of Labour Economics*, Volume III, Amsterdam: Elsevier.

Katz, Lawrence, Gary W. Loveman and David G. Blanchffower (1999)"A Comparison of Changes in the Structure of Wages in Four OECD Countries" in Richard Freeman and Lawrence Katz op. cit.

Kendrick, John W, (1961), *Productivity Trends in the United States*, Princeton [N.J.] Princeton University Press.

Keller, W. (2002). Geographic localization of international technology diffusion, *American Economic Review*, 52: 423-527.

Kiley, Michael, (1999) "The Supply of Skilled Labour and Skill-Biased Technological Progress", *Economic Journal*, Vol. 109 (458) pp. 708-24.

Kiiski, S. and M. Pohjola (2002). Cross-country diffusion of the Internet. *Information Economics and Policy* 14: 297-310.

Kremer, Michael and Eric Maskin, (1999) "Segregation By Skill and the Rise in Inequality" *MIT and Harvard Mimeo.*

Krueger, A. B. (1993). "How Computers have Changed the Wages Structure - evidence from microdata, 1984-1989." *Quarterly Journal of Economics*, 108: 33-60.

Krueger, Alan (1993), "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984-1989" *Quarterly Journal of Economics*, CIIX, 33-60.

Krueger, Alan B., and Jörn-Stefen Pischke (1997), "Observations and conjectures on the U.S. employment miracle," *NBER Working Paper*, No. 6146,

Krueger, Alan, (1997) "Labour Market Shifts and the Price Puzzle Revisited", *Princeton University, Industrial Relations Section Working Paper.* No. 375.

Krueger, Alan, (1998) "Reassessing the View That American Schools Are Broken" *Princeton University Working Paper.*

Krueger, Alan, (1999) "Measuring Labour's Share" *American Economic Review*, 89, 45-51.

Krugman, Paul, (1995) "Growing World Trade: Causes and Consequences" *Brookings Papers on Economic Activity*, pp 327-377.

Krusell, Per, and Lee Ohanian, and Victor Rios-Rull and Giovanni Violante, (2000) "Capital Skill Complementary and Inequality", *University of Rochester Mimeo.*

Krussel, P., Ohanian, L. E., Ríos-Rull, J. V., and Violante, G. L. (1997). "Capital-Skill Complementarity and Inequality: a macroeconomic analysis," *Federal Reserve Bank of Minneapollis staff report number 236.*

Kuznets, S. (1963). "Quantitative Aspects of the Economic-Growth of Nations," *Economic Development and Cultural Change*, 11: 1-80.

Landes, D., (1969). *Unbound Prometheus.* Cambridge: Cambridge University Press.

Lawrence, Robert and Matthew Slaughter(1993) "Trade and U.S. Wages: Giant Sucking Sound or Small Hiccup?" *Brookings Papers on Economic Activity*, pp. 161-226.

Leamer, Edward E., (1995) "Trade, Wages and Revolving-Door Ideas," *NBER Working Paper* No. 4716.

Lee, David S., (1999) "Wage Inequality in the U. S. During the 1980s: Rising Dispersion or Falling Minimum Wage?," *Quarterly Journal of Economics*, 114, 941-1024.

Machin, Stephen, John Van Reenen, (1998), "Technology and Changes in Skill Structure: Evidence from Seven OECD Countries," *Quarterly Journal of Economics*, 113 (4), Nov., 1215-44.

McKnight, L. W. and M. S. Shuster (2001), "After the Web: Diffusion of Internet Media" in McKnight, L. W. Lehr, W. and Clark, D. D. (eds.) *Internet Telephony*, Cambridge, Massachusetts, MIT Press: 165-190

Mobius, Marcus (2000), "The Evolution of Work" *MIT mimeo.*

Mokyr, Joel, (1992), *The Levers of Riches: Technological Creativity and Economic Progress*, Oxford University Press (N.Y.).

Mokyr, Joel, ed., (1993), *The British Industrial Revolution: An Economic Perspective*, San Francisco: Westview Press.

Murnane, Richard J. and Frank Levy, (1996), *Teaching the Basic New Skills*, New York, The Free Press.

Murphy, Kevin M. and Finis Welch "The Structure of Wages" *Quarterly Journal of Economics*, CVII (1992), 255-285.

Murphy, Kevin M. and Finis Welch, (1993), "Industrial Change and the Rising Importance of Skill," in S. Danziger and P. Gottschalk, eds., *Uneven Tides*, Russell Sage, New York.

Murphy, Kevin M. and W. Graig Riddell and Paul M. Romer, (1998) "Wages, Skills and Technology in the United States and Canada," in E. Helpman, ed., *General Purpose Technologies*, Cambridge, MA, MIT Press.

Nelson, Richard and Edmund Phelps (1966) "Investment in Humans, Technological Di□usion and Economic Growth", *American Economic Association Papers and Proceedings*, volume 56, 69-75.

Neumark, David, Daniel Polsky, and Daniel Hansen (1999) "Has Job Stability Declined Yet? Evidence for the 1990s" *Journal of Labour Economics*, 17, S29-65.

Newell, Richard, Adam Jaffee and Robert Stavins, (1999) "The Induce Innovation Hypothesis and Energy-Saving Technological Change" *Quarterly Journal of Economics*, CXIV, 907-940.

Nickell Stephen and Brian Bell (1996) "The Collapse in Demand for the Unskilled and Unemployment Across the OECD" *Oxford Review of Economic Policy* Vol 11, pp 40-62.

Nordhaus William D. (1998) "Quality Change in Price Indexes," *Journal of Economic Perspectives*, 12, 59-68.

Norris, P. (2001). *Digital Divide? Civic Engagement, Information Poverty & the Internet Worldwide.* New York; Cambridge University Press.

Nye, David E., (1990) *Electrifying America: Social Meanings of a New Technology, 1880-1940,* Cambridge: The Massachusetts Institute of Technology Press.

OECD Jobs Study Volumes 1 and 2 (1994).

Oliner, Stephen and Daniel Sichel, (1994) "Computers and Output Growth Revisited: How Big Is the Puzzle?" *Brookings Papers on Economic Activity,* pp. 273-318.

Piore, Michael and Charles Sabel, (1984), *The Second Industrial Divide,* Basic Books, New York.

Pohjola, M. (2002). The New Economy in growth and development. *Oxford Review of Economic Policy* 18: 380-396.

Quah, D. (2001). The weightless economy in economic development. In M. Pohjola (ed), *Information Technology, Productivity, and Economic Growth.* Oxford, Oxford University Press.

Reynolds, Lloyd G. (1951), *The Structure of Labour Markets; Wages and Labour Mobility in Theory and Practice,* New York, Harper.

Rogers E.M. (1983), *Diffusion of Innovations,* New York: The Free Press.

Romer, P.M., (1990) Endogenous technical change. *Journal of Political Economy* 98: S71-S102.

Rosenberg, N. (1982) *Inside the Black Box* Cambridge: Cambridge University Press.

Rubinstein, Yonna and Dani Tsiddon, (1998), "Coping with Technological Progress: The Role of Ability in Making Inequality so Persistent," *Tel-Aviv University working paper.*

Sachs, J. (2002). "The Global Innovation Divide," *National Bureau Economic Research,* www.nber.org/books/innovation3/sachs5-22-02.pdf. (Accessed on 21st March 2004).

Sachs, Jeffrey and Howard Shatz (1994) "Trade and Jobs in US Manufacuring" *Brookings Papers on Economic Activity,* pp. 1-84.

Schmitt, J. (1995). "The Changing Structure of Male Earnings in Britain, 1974-88," in *Differences and changes in wage structures,* (ed.) Freeman R and Katz L, University of Chicago Press.

Schmookler, Jacob, (1966), *Invention and Economic Growth,* Cambridge, Harvard University Press.

Schultz, Theodore, (1967), *The Economic Value of Education,* Columbia University Press, New York.

Schultz, Theodore, (1975) "The Value of the Ability to Deal with Disequalibria," *Journal of Economic Literature,* 13, 827-846.

Sen, A. K. (1997; 1st ed. 1973). *On Economic Inequality.* Oxford; Clarendon Press Oxford University Press.

Sichel, Daniel and Stephen Oliner, (2000), "The Resurgence of Growth in the Late 1990's: Is Information Technology the Story?" *Federal Reserve Bank Working Paper.*

Sichel, Daniel, (1997), *The Computer Revolution: An Economic Perspective,* Brooking Institution Press, Washington.

Stoneman, P. (2002). *The Economics of Technological Diffusion.* Oxford; Blackwell Publishers Ltd.

The Economist, (1999) "Computers and Wages," September 11,.

Tinbergen, Jan, (1975), *Income Difference: Recent Research,* Amsterdam: North-Holland Publishing Company.

Toffler, Alvin, (1981),*Third Wave,* Bantam Books, NY.

UTIP (2002). "UTIP UNIDO Theil 2001", Austin Texas: UTIP., can be found at http://utip.gov.utexas.edu/, accessed on 14th December, 2003.

Vindigni, A. (2002). "Income distribution and Skilled Biased Technological Change," *Princeton, Department of Economics - Industrial Relations Sections working paper number 464.*

Violante, Giovanni L. (1999), "Technological Acceleration, Skill Transferability and the Rise in Residual Inequality", *mimeo, University College London.*

Von Tunzelmann, G. N. (1978), *Steam Power and British Industrialisation to 1860.* Clarendon Press, Oxford.

Welch, Finis, (1970), "Education in Production," *Journal of Political Economy,* 78, 312-327.

Welch, Finis, (1973) "Black-White Differences in Returns to Schooling," *American Economic Review*, 63, 893-907.

Williamson, Jeffrey G. and Peter H. Lindert, (1980), *American Inequality: A macroeconomic History*, New York: Academic Press.

Williamson, Jeffrey, (1990), *Coping With City Growth During the British Industrial Revolution*, Cambridge, Cambridge University Press.

WITSA (2002). *Digital Planet 2002: The Global Information Economy*, World Information Technology and Services Alliance, Vienna, VA.

Wood, Adrian, (1994), *North-South Trade, Employment and Inequality: Changing Fortunes in a Skill Driven World, Oxford*, Clarendon Press.

Woolf, Arthur G., (1984), "Electricity, Productivity, and Labour Saving: American Manufacturing, 1900 - 1929," *Explorations in Economic History*, Vol. 21, 176-191.

World Bank (2003) "*World Development Indicators (WDI)*", Washington DC: The World Bank.