ICTs and the possibilities for leapfrogging by developing countries

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The last half of the twentieth century was marked by steady advance in the ubiquity of information and communication technologies (ICTs) throughout the industrialized world. The emergence of a significant "digital divide" between industrialized and developing countries is reproducing existing patterns of inequality with regard to these new technologies (Castells, 1996). During this same period, however, substantial achievements in the few countries which succeeded in narrowing the economic divide separating them from the industrialized world often involved the export-oriented production of ICTs (Kim, 1997; Hobday, 1995b; Amsden, 1989) or, less commonly, their effective use in improving productivity or creating new markets. The continuing rapid decline in the prices of these technologies and the accompaniment of these price reductions with a growing range of applications suggest that they offer further opportunities for economic growth.

In particular, ICTs are unique in a number of ways compared with the leading industries of the past that were responsible for industrial growth and development, such as steel, chemicals, and machinery. In many applications, and in some types of production, the conditions of entry for using and, in some cases, for producing ICTs do not require massive investment in fixed plant capacity or infrastructure or in the accumulation of experience. Moreover, ICT applications often appear to be complementary to efforts to improve the quality, speed and flexibility of production, offering a compensating advantage against existing shortcomings in production capacities (Lal, 2000). Because virtually all of the components and many of the systems embodying these technologies are internationally available from highly competitive

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markets, and are easily transportable, they appear to be readily transferable to whichever country can make productive use of them.

All these features suggest that ICTs have the potential to support the development strategy of "leapfrogging," i.e. bypassing some of the processes of accumulation of human capabilities and fixed investment in order to narrow the gaps in productivity and output that separate industrialized and developing countries. Looking to the future, the potential for leapfrogging seems even brighter owing to the emergence of Internet technologies, which are supporting the global flow of information and the emergence of a "virtual" cyberspace domain, in which many of the constraints of time and distance are erased. Internet technologies are particularly important because they provide an unprecedented variety of new and "open" formats for the distribution of information and the establishment of inter-organizational linkages.

Are the claims made for the leapfrogging potential of these technologies realistic? Should developing countries divert scarce resources from other projects in an attempt to tap their potential? And, if they do, what are the scale and timing of the returns that might be expected? These questions are becoming ever more central as claims are made in the industrialized world that businesses failing to develop effective e-commerce or information system strategies are doomed, and as major efforts are undertaken to close domestic digital divides separating regions or small and large businesses.

Difficulties of achieving "technology transfer"

Any evaluation of the potential for leapfrogging offered by ICTs depends upon a clear understanding of the meaning of this strategy and of factors that might affect its planning or implementation. As noted, leapfrogging means bypassing stages in capability building or investment through which countries were previously required to pass during the process of economic development. This suggests that development follows a linear, predictive path, with well-defined stages (Rostow, 1962). While this theory is now generally rejected at the macroeconomic level, it persists at the level of individual firms and industries, because of the evidence that technological progress is a cumulative and incremental process. Capabilities are often constructed incrementally on the basis of experience, and the nature and extent of experience influence the evolution of capabilities in firms and industries. It is important, however, to distinguish between progress at the technological "frontier," involving the discovery and invention of entirely new knowledge and capabilities, and progress in adapting and imitating technologies already in use. The latter type of technological progress is often associated with the unfortunate term "technology transfer", which suggests that firms can upgrade their capabilities overnight by a suitable acquisition of equipment or know-how.

The difficulties of achieving technology transfer are among the principal reasons for the difficulties of achieving sustained growth. If it were possible, for example, to reproduce in developing countries the physical productivity of techniques employed in industrialized countries, the lower costs of purchased inputs, such as labour, would provide developing countries with substantial competitive advantages in substituting for imports and in gaining a share in international export markets. This is not possible for many reasons, several of which are pertinent to the issue of leapfrogging.

First, few (if any) process technologies are so well specified that the equipment needs only to be installed and switched on, for purchased inputs to be transformed into finished outputs. In practice, technologies that are new to the experience of a company, wherever it is located, require a process of learning and adaptation during which skills are acquired and adaptations are made (Kim, 1997; Hobday, 1995a). These abilities for learning and adaptation have come to be referred to as "absorptive capabilities" (Cohen and Levinthal, 1990). The more frequent, and extensive incidence of technological change in the industrialized world suggests that more effective absorptive capacities have been constructed by enterprises in industrialized countries. While this hypothesis may be valid on average or in aggregate, it does not necessarily apply to every industry or company. Efforts to build absorptive capacity are a specific strategy for economic development and a prerequisite for technological leapfrogging.

Second, technology transfer may be limited by the functioning of markets for equipment or knowledge. If such markets are monopolies or underdeveloped, it may not be possible to acquire specific technologies. A particular concern in recent years has been that abilities to imitate or reproduce existing technologies are limited by intellectual property rights (IPRs) that apply globally as a result of international conventions (Correa, 1996). Such conventions are intended to create incentives to innovation and to promote market exchanges in technological knowledge, but they may also be used to block access to relevant technologies. It may be argued that a potential user of technologies subject to intellectual property protection who can produce output at a lower cost should be able to generate the revenue to pay an attractive licence fee to the technology owner. In practice, however, there are many possible reasons why owners may not choose to negotiate, including their desire to use the property right to retain control of domestic or export markets or to retain their leadership in the technological area by benefiting from experience in their own, exclusive use of the technology. The market conditions for equipment and knowledge exchange are therefore important issues to consider when assessing the feasibility of technology transfer and leapfrogging (Soete, 1985).

Third, a technology rarely stands independently; usually it relies upon a variety of complementary technologies and capabilities. In other words, most technologies are systemic and include linkages with other industrial sectors. The development of markets for complementary technologies is therefore likely to affect technology transfer and leapfrogging strategies. For example, the capacity to produce electronic systems is likely to require inputs from the fabricated metals or plastics industry to produce cases or enclosures. In industrialized markets, the linkages between industries are usually well developed and markets for intermediate inputs have often become competitive, features which support the effective and rapid supply of needed complementary technologies and components. Industries differ in the extent to which they require complementary technologies and in the relative difficulties of market development, in cases where new products and services are needed.

Fourth, technologies are a means to an end, namely, the production of goods and services. The markets for these goods and services may differ substantially in geographical scope, design complexity, or marketing sophistication. In each of these cases, market development is likely to require investment in capabilities and in an infrastructure of commercial relationships with other companies. These requirements can be collectively termed "downstream integration requirements". A particular technology may be capable of producing products and services with a range of different downstream integration requirements. Consumer goods often present a higher level of these requirements than capital goods. In particular, Hobday argues that one of the most elusive goals of electronic firms in the "new" economy is achieving an "own brand" presence in world markets, when this involves all of the downstream integration requirements noted above (Hobday, 1995a).

Need for superior market performance

Any strategy for technological leapfrogging must first address the issues of technology transfer, absorptive capacities, access to equipment and know-how, complementary capabilities and downstream integration requirements. In addition, however, a new, leapfrogging technology must prove to be superior in market performance relative to competitive alternatives. As Rosenberg observed in the case of new "frontier" technologies, early developments and applications are often fragile, and the challenge of a competitive alternative stimulates the improvement and adaptation of existing technologies (Rosenberg, 1976). The same applies to transferred technologies of all types. When the transferred technology is one that leapfrogs earlier developments, the period of performance improvement and adaptation is likely to be longer and to face greater hazards from existing competitive alternatives. These problems may partly be overcome by technologies that permit the introduction of fundamentally new products and services. However, in this case, an offsetting factor is that downstream integration requirements are likely to be larger. In particular, the marketing requirements of introducing these new products and services are likely to be substantial and to resemble the "own brand" problem, even in domestic markets.

Performance in the use of a leapfrogging technology involves the development of skills and organizational capabilities. Again, the problem is whether prior experience acquired in earlier stages of the technology's development contributes to the creation of these new skills and capabilities. The magnitude of this problem will depend upon the technology chosen. For example, current generations of equipment for creating printed circuit boards involve automated component layout routines and the generation of "screening patterns" for etching the board and establishing electrical conduction paths. These techniques bypass previous generations of skills involving manual drafting of the circuit boards' patterns and layout. Thus, in this case, the skills accumulated through use of the preceding technology are largely irrelevant to the application of the current technology. Not only is the earlier technology bypassed, but many of the skills associated with it are bypassed, as well. Of course this is not true of all technologies or of all applications of any particular technology. The development of miniaturized printed circuit assemblies suitable for devices such as watches is not likely to profit greatly from the technique noted above, and previous experience with miniaturization is likely to create "spillovers", transfers of knowledge and experience to later technological generations.

The foregoing outline of issues relevant to technological leapfrogging may be applied to the production and use of ICTs. However, it is important to observe at the outset that only a limited number of generalizations can be made about the full range of ICTs. The prerequisites for leapfrogging and performance issues vary substantially *within* ICTs. Thus, though the following analysis suggests that certain characteristics of ICTs may help solve problems in meeting prerequisites and achieving performance, exceptions will also readily arise. Moreover, it is particularly difficult to make generalizations about how to achieve adequate performance in the *use* of ICTs. Answers have yet to be found to many questions about the factors affecting relative performance in the use of ICTs across organizations or sectors in industrialized economies. There is little reason to believe that the answers to these questions will be easier for developing countries to find. Thus, the optimistic tone of the following discussion should be tempered by recognition that the definition and application of best practice in the production or use of ICTs in the industrialized world provide only a modest assurance of success. An even more conservative attitude is appropriate towards promises of successful performance in developing countries, where there are the additional complexities of technological leapfrogging. Nonetheless, it is possible to demonstrate a number of cases where such successful performance has been achieved. Selected successful examples are described in boxes 1-3.

Prerequisites for success in technological leapfrogging

Develop absorptive capacities to produce or use ICTs

The first prerequisite for technological leapfrogging is the existence of absorptive capacities to produce or use ICTs. Both types of capacity benefit from the widespread dissemination of information about the "digital revolution." Indeed, the variety and comprehensiveness of texts and instruction manuals devoted to ICTs are remarkable. Entire publishing companies are devoted to the production of these materials and a growing array of useful information is available from Internet sources. While the availability of such codified information certainly does not automatically create absorptive capacities, the availability of instruction manuals, user guides, and design manuals on ICTs is unusually large (Cohendet and Steinmueller, 2000).[1] By comparison, the contemporary documentation for industries such as chemicals or machine manufacture is very small and often academically oriented, neglecting specific detail about available equipment and techniques. Absorptive capacity in many ICT industries is further assisted by the relatively modest investments required to prototype new designs or experiment with the integration of sub-systems (including software designs). For some important ICTs, such as telecommunication switches and networks, small-scale prototyping is not a meaningful option. Nonetheless, in terms of both quantity and value, single printed-circuit board systems account for the largest share of electronic systems that are produced. In both production and use of ICTs, software tools provide the basis for both system integration and the creation of new applications. These tools continue to be improved and are both extensively documented and supported by global networks of users at all technical levels. Note also that such users are now linked through the Internet, a development which distinguishes the current era from earlier periods of industrial development.

Recently, the development of the "open source" software movement has further enhanced opportunities for individuals with access to the Internet also to gain access to the tools and documented explanations about how advanced software products may be created. Open source software such as the Linux operating system and Apache Web Server application software are products that have been produced by individuals working on a voluntary and unremunerated basis to create complex software products. The producers of open source software are intensive software users who receive a variety of personal, although not necessarily monetary, benefits from participating in the collective activity of open source software creation. Many of the standards employed in the open source software community are derived from the research community (Unix) or the Internet community (HTML) which are extensively documented on the World Wide Web. Taking advantage of the opportunities provided by the availability of technical information related to open sources software requires a background knowledge that needs only a relatively modest level of technical education and, perhaps even more important, access to personal computers and (ideally) to the Internet. It is important to realize that many of the leading programmers in the industrialized world are self-taught, despite the creation of the university discipline of computer science and the awarding of degrees in this subject. However, for every person who proves capable of developing an understanding of ICTs in this way,

[1] For a recent review of the issues surrounding codified knowledge, see the special issue of *Industrial and Corporate Change* on this subject (Vol. 9, No. 2, 2000), to which Cohendet and Steinmueller (2000) provide an introduction.

Box 1. Malaysia's Government Multipurpose Card (GMPC) and Payment Multipurpose Card (PMPC)

A flagship technology being developed in the Malaysian Multimedia Super Corridor involves “smart-card” technologies. A unique feature of the PMPC project is the combination of the electronic “purse” functions normally associated with telephone service payment cards with credit and debit card services. The GMPC and PMPC projects are based on a prior experiment successfully implemented at the 1998 Commonwealth Games. A medium-scale deployment is planned for the first quarter of 2001 with the distribution of 2 million GMPCs, several thousand card-acceptance devices, and the infrastructure to support the system in the Multimedia Super Corridor and Kuala Lumpur areas. The GMPC is expected to provide citizens with convenient and secure links to government services and to provide the means to make small payments. According to the Multimedia Super Corridor authority the smart cards themselves, as well as a substantial part of the technology being used for the card access devices, are being devised by domestic companies. Nain and Anuar (1998) note that development of a similar card, including passport, driver's licence, and health information on a single card, would be very difficult in industrialized countries because of concern about confidentiality and government control. The combined purposes of the card are expected to yield unique services and to provide a new basis for learning about useful applications of smart-card technology.

Source: See http://www.msc-expo.com.my/mpc/index.html, last accessed 05/09/00.

dozens, and perhaps hundreds, achieve only a rudimentary “user level” understanding. A principal implication of the digital divide is that societies that prove able to offer more extensive access are likely to generate a larger supply of such highly capable, self-taught persons.

Such optimism about the development of absorptive capacities must be tempered by a recognition of the limitations to self-training and education. The educational background required to make use of the extensive array of documentation primarily in the English language, the facilities and networks required to make it accessible, and the development of management capabilities to lead the development of serious products and services all require significant investments. When assessing the potential for leapfrogging, it is important to acknowledge that the basis for bypassing earlier stages of development is the ability to access (with a reasonable investment in skills and equipment) the essential features of a contemporary technology. It is not necessary, for example, to learn to keypunch cards for mainframe computers in order to learn computer programming although prior to 1970 this was a stage in the acquisition of every programmer’s professional skills.

Access to equipment and know-how to make productive use of latest ICTs

The second prerequisite for a strategy on leapfrogging is access to the equipment and know-how needed to make productive use of later stages in technological development, without having to develop technological precursors. As was noted earlier, the existence of intellectual property rights (IPRs) and their global enforcement often raise real or imagined issues

Box 2. Technological leapfrogging in the development of a national power grid for ICT applications

Shortage of electricity is a major deterrent to the use of ICTs, a problem which has been addressed by two particular projects in rural South Africa. One implements digital telephone services using solar-generated electricity stored in batteries. A second project uses the solar-panel and battery array to support the use of ICTs in schools. The project aimed to supply all 16,400 remote schools by the year 2000.

Source: Butcher and Perold (1996), quoted in Mansell and Wehn (1998), p. 101.

about constraints on access to state-of-the-art equipment and know-how that new entrants may face. As suggested in the preceding discussion of absorptive capacities, access to the know-how for the use and, in many cases, the production of ICTs is unusually easy compared with the situation in other industries.

However, IPRs do create real constraints in the implementation of strategies on leapfrogging in the ICT industries. These constraints vary widely, depending on the specific technologies and products or services in question, and a major practical problem is assessing whether IPR constraints are likely to apply. For example, in the production of a plug-in card for a personal computer, it is relatively straightforward to acquire the equipment and know-how to implement a new design that uses off-the-shelf components. However, significant investment may be required to discover whether elements of the hardware or "embedded" software (a common feature in contemporary systems constructed using programmable components) infringe existing intellectual property. Should a design infringe a patent, the costs and delay involved in negotiating a licence or changing the design to stop it infringing may greatly reduce the product's commercial prospects.

The problems of IPR risks are heightened by the complex and multilayered nature of IPR enforcement. For example, in the United States, the owner of a patent may seek to bar imports of "articles that – (i) infringe a valid and enforceable United States patent or a valid and enforceable United States copyright registered under title 17; or (ii) are made, produced, processed, or mined under, or by means of, a process covered by the claims of a valid and enforceable United States patent" (19 USC S1337). The agency responsible for receiving these complaints is the United States International Trade Commission (ITC) and the statute quoted here is part of the enabling legislation governing that agency. The ITC is required to provide timely public notice of complaint and to publish within 45 days an anticipated schedule for the final resolution of any complaint. The principal remedy available to the complainant is the barring of infringing articles from importation into the United States market, using the powers of the United States Treasury Department, which operates the United States Customs Service. The aim of providing the ITC with investigative powers and requiring it to resolve complaints was, in part, to provide United States patent holders with a central authority for pursuing

Box 3. Aditi Technologies: Company technological leapfrogging in the service sector

Aditi Technologies, one of the companies participating in the high-technology developments in Bangalore (India) has pioneered ICT services in customer relationship management and computer-aided technical support. Aditi's technological leapfrogging was based on the experience gained by its founder, Pradeep Singh, when working for Microsoft, where the increasing technical complexity of "developer applications" (the languages and support tools used to design new software) was placing increasing strain on technical support capacities. Software developers are highly sophisticated and demanding users who often ask complex questions, many of which have been answered in some other context. Meeting these customers' needs requires sophisticated capabilities for referring questions to appropriate experts and following up on the results of a series of enquiries, capabilities that must be supported by detailed and easily accessible electronic records of the history of problem-solving activity. Although Aditi does offer telephone support services, its primary advantage in the global market is managing email support, a service that requires its own software for customer support. The Aditi system supports high-priority service to favoured customers and the means to identify and notify particular user communities *en masse*. It also provides the means for monitoring productivity and customer satisfaction, giving clients (such as Microsoft) accurate information about the quality of the services it provides. Aditi's success is an indication of the growing opportunities for relatively technologically sophisticated workers in developing countries to develop a means to trade their services in global markets. Although Aditi has achieved a globally competitive position in this specialized market, the tools that enabled its success are capable of handling support for smaller national markets and in languages other than English. A key feature of this enterprise's success has been the technological leapfrogging it achieved by proceeding directly to ICT-based tools for managing the information flows stemming from email communication.

Source: Original research by Dr. Jane Millar, SPRU.

claims of patent infringement against foreign companies. Further claims against United States companies that incorporate infringing imports in their products may be undertaken in the Federal Courts of the United States. It must be emphasized, however, that many of the complaints made to the ITC are resolved through settlement processes rather than through the courts. As of September, 2000, 51 items were subject to outstanding exclusion, five of which concerned ICT.[2] Of these five items, two concerned integrated circuit memories, two data communications, and one involved electronic hardware emulation devices and software. While these decisions were no doubt significant to the companies concerned, they involved very few products. The existence of only a few sanctions should not be taken as demonstrating the insignificance of the problem, however, as a substantial number of potential cases may have been resolved through the threat of complaint followed by undisclosed settlements or the abandonment of the United States market.

[2] http://www.usitc.gov/ouii/exorder.pdf, last accessed 28 September, 2000. Two additional exclusion orders relating to coin-operated video games are omitted from the count because the infringement involved trademark violations and the "simulation of trade dress", terminology used in cases where the respondent is attempting to create a facsimile of a branded product, including the product's "look and feel". It is difficult to commit this offence inadvertently.

Though not as great as the downstream integration requirements to be discussed shortly, such problems are likely to prove significant. Concerns about this issue have been exacerbated by the extensive IPR claims of some producers, who are often motivated by the desire to be able to respond to claims made by other companies with proposals to cross-licence IPRs.[3] From the perspective of a company in a developing country, however, the proliferation of IPR claims and the increasing incidence of enforcement actions are warning signs that IPR-based barriers to entry are beginning to appear in the ICT industries. In many cases, it may be possible to overcome these barriers by agreeing some type of licensing or joint venture activity with an experienced company, whereby the new entrant gains access to a pool of applicable technology within which non-infringing systems may be defined. For companies with greater investment capabilities, the legal and technical advice to avoid these problems is readily available.[4]

Though the potential for IPR-based barriers should be taken seriously, there are relatively few ICTs on which IPRs have supported effective monopolies or cartels. This is because of computer software's inherent flexibility. This flexibility stems from the many different ways to write computer programmes to achieve the same function and thus to avoid duplicating a specific "expression" (a specific sequence of computer instructions) in creating software. The *expression* of an idea rather than an idea itself is protected by copyright and copyright remains the principal means of IPR protection for software. The variety of alternative and functionally equivalent expressions, and the fact that the main added value of many ICT products and services lies in software design and downstream integration investments, substantially reduce the barriers to imitation. In the production of ICTs, the world market in capital goods is large and highly competitive. Gaining access to production technology is a far less significant problem than employing it productively and creating a competitive world-class product. This production technology is used to create certain types of product, particularly in the area of telecommunications equipment. To date, however, these barriers have been confined to relatively narrow, though large, markets.

Need for complementary technological capabilities

It is particularly difficult to make general statements about the third prerequisite, the need for complementary technological capabilities. This is

[3] Several recent cases brought before the United States ITC are recorded as being resolved by the agreement of the parties to a cross-licensing arrangement.

[4] This issue will continue to be contentious. Development of strictly non-infringing substitutes is more expensive than "cutting close" to the often ill-defined and expanding boundaries of intellectual property claims. The mechanisms for resolving disputes are likely to remain imperfect, given the absolute rights provided to intellectual property holders.

because the extent of systemic integration between ICT products and services varies enormously. On the one hand, thousands of ICT products can be characterized as "stand-alone" systems. Although these systems may integrate several different technologies, the interfaces between these technologies may be relatively straightforward, allowing the partitioning of sub-systems and the design process. Unfortunately, conclusions cannot be drawn about the need for complementary capabilities simply from the stand-alone quality of a system. Modern plain-paper copies have a substantial electronic content that relies upon information technology. Developing a globally competitive plain-paper copier requires very substantial capabilities in integrated mechanical and electronic technologies — which Kodama calls a "mechatronics" capability (Kodama, 1991).

It can, however, be stated that modern ICTs are modular and that the interconnections between components and sub-systems are based on well-specified rules designed to increase capacities for configuring new systems. In practice, electronic designs do involve interdependencies and unexpected "bugs" or problems occur that must be resolved somewhere in the design and testing process. However, the knowledge needed to solve these problems is likely to be confined to the specific domain of electronic and digital circuit design, and not to extend to other bodies of knowledge. As the design of an ICT system incorporates an increasing number of interfaces with non-electronic sub-systems, the complexity of the design process increases, as does the need for complementary capabilities. In developing countries, vexing problems with electronic systems often occur because of the fact that electrical power sources are often subject to intermittent voltage drops or spikes, or to variations in the cycle frequency of alternating current. Systems designed for relatively constant voltage and cycle frequency may prove unreliable when these conditions are not met. Similarly, components' environmental specifications regarding temperature and humidity may lead to problems in the use of electronic systems in some developing country contexts. Even when such additional complications are taken into account, the extent to which ICTs require the integration of technologies from outside the electronics domain is modest, compared with many other technologies. For example, the issues needing to be addressed in a chemical or steel plant span a wide array of disciplines, many of which are far less documented than the issues involved in the design and use of ICTs.

The complementary capacities required for ICT design and use increasingly involve knowledge of software. This is because ICT systems contain an increasing number of programmable components and because the use of ICT systems to produce services involves software designs of increasing complexity. As noted earlier, an important consequence of the digital divide is the problems experienced by developing countries in training a sufficient number of individuals with software programming skills, because of the links between skills-building and access to the relevant technology.

As is common in other situations occurring in developing countries, the scarcity of human resources leads to lower threshold levels of involvement and opportunity (Heeks, 1999).[5]

Innovation through "recombination" of ICT knowledge

In industrialized countries, a large number of persons with ICT skills are dispersed throughout the economy, which means they have numerous opportunities to employ their knowledge of ICT potentialities in specific problem-solving situations. The generation of such knowledge through "recombination" is a major, perhaps even the primary, mechanism for innovation in ICT application in industrialized countries (Gu, 1999). Though many of these innovations are applied in local and idiosyncratic ways, others become candidates for entrepreneurial initiatives, for the construction of products and services that can be commercialized either through the formation of new companies or the development of new businesses by existing companies. However, examples of the recombination of technologies are not confined to industrialized countries. In both China (Gu, 1999) and Thailand (Poapongsakorn and Tonguthai, 1998, pp. 172-3), the problems involved in the proper display of their written languages have provided an opportunity for domestic firms to produce "graphics cards," a key component in personal computers. As Poapongsakorn and Tonguthai (1998) note, however, the rate of evolution of personal computer technology presents a major challenge to Thai producers (ibid., p. 173). This is an important problem, for the recombination strategy for system products requires regular updating of knowledge about complementary components from foreign sources.

Variety generation is further aided by the activities of venture capitalists whose purpose is not only to finance the commercial development of potentially profitable new ideas, but also to identify and help oversee the management of the diverse human resources required to enable new companies to grow. It is important to emphasize that the entire process (from generation of application ideas to the growth of new companies) shares many of the properties of an ecological system. Over the millennia, the strength of a particular ecological system has largely depended on the trial of new species, many of which are selected out before they reach maturity. In ICT-related businesses, the evolutionary clock ticks much more rapidly, and thousands of ideas are winnowed out each year.

The system for generating ideas for ICT applications that has evolved in industrialized countries may seem a rather imprecise "complementary technological capability." However, it is particularly difficult to reproduce. Because of the advantages it offers in testing new ideas, it is difficult to see

[5] In addition to many of the other issues addressed in this paper, Heeks (1999) addresses this issue by considering how involvement with industrialized countries often supports software businesses in developing countries.

how developing countries can emulate industrialized countries in thus capturing the potential of ICT applications. Capturing part of the potential may, nevertheless, give a substantial impetus to economic growth. Because innovation in ICT applications involves a specific and localized recombination of knowledge, and because no single country has a monopoly on brilliant insights, there are real prospects for developing countries to generate commercially significant new ideas about ICT applications. Though these countries are unlikely to enjoy as favourable an environment for translating these ideas into entrepreneurial initiatives as do industrialized countries, the ideas will nevertheless emerge. Because the specific situations in which they are produced are likely to differ from those prevailing in the industrialized world, some of these ideas will differ significantly from the knowledge and capabilities developed by companies in industrialized countries. Some optimism is therefore warranted about the prospects for developing countries to participate in innovative leadership.

There is cause for more optimism as regards the prospects for developing countries to use their knowledge about complementary technologies in order to leapfrog stages in the production and use of ICTs. The industrialized world's "ecology of ideas" both enlarges the supply of intermediate ICT products and services that developing countries can acquire, and increases the competition among those products and services. Substantial spillover potential exists, and solving problems of access to complementary technology and knowledge should also be perceived as a means of improving access to and distribution of knowledge in developing countries (David and Foray, 1995). It is important to recognize that much of this knowledge is likely to reside in smaller, specialized companies that do not have global reach.

Achieving downstream integration capabilities

The fourth prerequisite, downstream integration capabilities, encompasses the most difficult issues for developing countries in achieving technological leapfrogging. In this area, however, the problems faced by developing countries concern not only ICTs, but also market development and growth in virtually every sector. These problems include generally smaller market size, logistical issues related to the global delivery of products and services, and problems in marketing products and services where substantial efforts must be made to convince users of their utility, reliability and value. These problems may be partly mitigated by particular circumstances. Some developing or middle-income countries have access to large internal markets (e.g. China) or large regional markets (e.g. Mexico, with its proximity to Latin American markets). The value-to-weight ratio of many ICT products is high, easing some of the logistical problems in their delivery. ICT services may increasingly be delivered through the use of international data communication facilities, where leapfrogging technological developments involving satellites and fibre cable networks offer infrastructures of comparable quality (though higher cost) than those available in industrialized countries. Many ICT products and services are intermediate or producer goods sold to users who are capable of making an independent evaluation of their utility, reliability and value, rather than having to rely on brand names or other attributes created through sophisticated and expensive marketing efforts. However, such mitigating circumstances do not apply everywhere, and in other respects the problems of developing markets for ICT products and services are similar to or, because of their complexity, worse than those for other industrial products.

Where are the promising opportunities for technological leapfrogging?

In cases where the prerequisites can be met, attempts at technological leapfrogging *will* be made, i.e. such initiatives will occur, either within existing organizations or through the formation of new organizations. The performance of these initiatives will then determine whether significant contributions to economic growth and industrial development are made. Few generalizations can be hazarded about how technological leapfrogging can achieve the performance in the supply of ICTs necessary to meet the challenges of international competition in the ICT industries, as these challenges tend to be highly market-specific. The examples featured in boxes 1-3 illustrate how, once the basic prerequisites are met, specific initiatives can then rise to these challenges. Analysis of such examples suggests that promising opportunities exist in the following markets:

- sub-systems that are intended to be integrated in more complex electronic products (reducing the downstream integration requirements);
- stand-alone producer goods whose technical qualities will be assessed by relatively sophisticated customers (reducing downstream integration requirements and the need for complementarities); and
- services, including software and information services (reducing the problems of technological access).

In all cases, the problems of absorptive capacity are irreducible prerequisites for success in technological leapfrogging.

Somewhat broader, positive conclusions can be drawn about the potential for use of ICTs. Personal computers and specialized microprocessor-based hardware systems are used to monitor and measure the performance of production operations as well as to provide logistics, customer support, and supplier communication. These are all areas in which relatively inexpensive applications offer real opportunities for ICTs to contribute to productivity and economic growth. Deriving benefits from these types of ICT application involves no fundamental technological difficulties: virtually all the problems are organizational. In this context, leapfrogging involves bypassing stages of management development that characterize organizations that have extensive hierarchies and large numbers of individuals in middle management positions. The development of systems providing persons directly involved in production processes or service delivery with more sophisticated tools to perform their jobs offers very real opportunities. The most significant barriers occur in making the difficult changes in absorptive capacity required to exploit these opportunities. These changes involve conferring considerable unsupervised responsibility on the workers concerned and, perhaps even more difficult to achieve, they require managers and other "controllers" of the labour force to devise ways of reducing their own responsibilities. These organizational changes are often difficult in industrialized countries; they are likely to be even more difficult to achieve in developing countries.

It is important to address one final issue. Readers from developing countries will note that an important issue has been overlooked in the preceding discussion, namely, whether the entrepreneurial efforts of technological leapfrogging will be launched by domestic or foreign-owned organizations. This is a sensitive issue that often involves nationalist sympathies or historically based antagonisms. It *does* matter whether decisions about the future are taken abroad because the desire for self-determination is universal. Concern is repeatedly expressed that countries risk being locked into patterns of foreign control that preclude national self-determination. Although the preceding discussion has contested the claim that IPRs necessarily have this effect, the requirements for effective technological leapfrogging remain substantial. Discussion of how to develop policies to ensure an effective balance between the respective roles of foreign and domestic initiatives is beyond the scope of this article — although some will regard the search for these policies as *the* most important issue.

The experience of the newly industrialized countries is that achieving this balance has required substantial governance. Historically, this governance has involved measures to control trade and investment in order to support infant industries that were held to high performance standards. These policies are no longer possible within the framework for international trade established by institutions such as the World Trade Organization and the most recent General Agreement on Tariffs and Trade (GATT). In many countries, the governance of infant industries did not result in internationally competitive products or services; indeed the most common result was ageing infant industries opportunistically enjoying local market power within protected markets, rather than technological leapfrogging. Although a liberal international trade environment greatly reduces the possibility of opportunistic behaviour in which domestic firms dominate protected markets, it also heightens the performance requirements for domestic initiatives. In the international trade environment, the hurdles to technological leapfrogging are growing higher. As a consequence, developing country firms must increasingly rely upon strategies of upstream and downstream involvement, in order to achieve effective results. The difference between "latecomer" and leading and following economies noted by Hobday (1995a) is thus likely to persist, although substantial positive benefits may nonetheless accrue to latecomer strategies such as technological leapfrogging.

Conclusion

This article began by asking three questions, to which limited answers can be provided. Are the claims made about leapfrogging realistic? The claim that technological leapfrogging in the production and use of ICTs is possible is clearly supportable. The discontinuity of technological change in electronics, the availability of knowledge about key technologies sufficient to create or exploit applications, and a broad and competitive market for the producer and user tools necessary for ICT applications all provide evidence that technological leapfrogging is possible.

Should developing countries divert scarce resources from other projects in order to attempt to tap their potential? In this area, proponents of leapfrogging strategies bear a heavy moral weight, since the consequences are literally a matter of human life and death. At the same time, failure to initiate the process of building absorptive capacities to use ICTs only defers the likely growing need to participate in international export markets, to maintain the competitiveness of domestic industries, and to make more productive use of available resources. A much more agnostic position is appropriate on the issue of ICT production. Potential for some types of ICT production exists in virtually every country although relatively few will be able to assemble the absorptive capacities, complementary industries, and downstream integration capabilities needed for these production activities to play a significant role in economic growth and development. Though a growing number of countries will be able to create "enclave" ICT production based on direct foreign investment and a well-educated labour force, the temptation to overestimate the spillover from these investments should be resisted. This is why this article has emphasized the need to address all the prerequisites for leapfrogging.

The golden question concerns the scale and timing of the returns that may be expected from investments in ICTs. If it could be answered with certainty, all the other issues raised in this article could be restated in a traditional cost-benefit framework. This can be achieved in only a few cases, most of which involve specific plans for ICT production. More generally, however, it is not appropriate to consider these issues in terms of investing in a production plant for a known market. Acquiring ICT-related capabilities is rather like learning a language. Knowledge of ICTs provides a different perspective on the world and enables one to see that certain long-held assumptions are simply rather peculiar habits of thought. This shift in perspective can result in a clearer perception of the potential for innovation, beginning perhaps by using relatively simple tools to improve the productivity and expand the capacity of existing methods for producing goods or delivering services. But ICT-related knowledge can also provide the basis for much more profound innovation. ICTs can provide the tools with which people entirely restructure the ways in which they interact, and these new ways may bypass the construction of human and machine systems that would have been the only alternative. By learning the "language" of ICTs, people can discover new approaches to the social and physical world. As with any fundamental new technology, the gains from such new tools can never be fully anticipated. They remain to be demonstrated by those with vision and courage.

References

Amsden, Alice H. 1989. *Asia's next giant: South Korea and late industrialisation*. Oxford, Oxford University Press.

Butcher, N; Perold, H. 1996. *Technology Enhanced Learning Investigation (TELI) in South Africa: A discussion document*. Report of the Ministerial Committee for Development Work on the Role of Technology that will Support and Enhance Learning.

Castells, Manuel. 1996. *The rise of the Network society. Volume 1 of The information age: Economy, society and culture*. Oxford, Blackwell.

Cohen, Wesley M.; Levinthal, Daniel A. 1990. "Absorptive capacity: A new perspective on learning and innovation", in *Administrative Science Quarterly* (Ithaca, NY), Vol. 35, No. 1, pp. 128-152.

Cohendet, P.; Steinmueller, W. Edward. 2000. The codification of knowledge: A conceptual and empirical exploration, in *Industrial and Corporate Change* (Oxford), Vol. 9, No. 2, pp. 195-210.

Correa, Carlos M. 1996. "Strategies for software exports from developing countries", in *World Development* (Washington, DC), Vol. 24, No. 1, pp. 171-182.

David, P.; Foray, D. 1995. "Accessing and expanding the science and technology knowledge-base", in *STI Review: OECD Science, Technology, Industry* (Paris), No.16 (Autumn), 1995, pp. 13-68.

Ernst, D.; Ganistsos, T.; Mytelka, L. (eds.) 1998. *Technological capabilities and export success in Asia*. London/New York, Routledge.

Gu, S. 1999. *China's industrial technology: Market reform and organizational change*. London, Routledge.

Heeks, R. 1999. *Software strategies in developing countries*. Development Informatics Working Paper Series No. 6. Manchester, Institute for Development Policy and Management, University of Manchester.

Hobday, Mike. 1995a. "East Asian latecomer firms: Learning the technology of electronics", in *World Development* (Washington, DC), Vol. 23, No. 7, pp. 1171-1193.

—. 1995b. *Innovation in East Asia: The challenge to Japan*. Cheltenham, Edward Elgar.

Kim, Linsu. 1997. *Imitation to innovation: The dynamics of Korea's technological learning*. Boston, MA, Harvard Business School Press.

Kodama, F. 1991. *Analysing Japanese high technology industries: The techno-paradigm shift*. London, Pinter.

Lal, Kaushalesh. 2000. *Adoption of information technology and its consequences in a development context*. Unpublished Ph.D. Thesis. Rotterdam.

Mansell, Robin; Wehn, Uta (eds.). 1998. *Knowledge societies: Information technology for sustainable development*. Oxford, Oxford University Press, published for the United Nations Commission on Science and Technology for Development.

Nain, Zaharom; Anuar, Mustafa K. 1998. *IT strategies in Malaysia: The multimedia super corridor*. Paper presented at the International Conference on Information Technologies and Social Development organized by the United Nations Research Institute for Social Development, 22-23 June, Geneva.

Poapongsakorn, N.; Tonguthai, P. 1998. "Technological capability building and the sustainability of export success in Thailand's textile and electronics industries", in Ernst, Ganistsos and Mytelka, pp. 157-210.

Rosenberg, Nathan (ed.). 1976. *Perspectives on technology*. Cambridge, Cambridge University Press.

—. 1976. “Factors affecting the diffusion of technology”, in Rosenberg, 1976.

Rostow, W. W. (ed.). 1962. *The stages of economic growth*. Cambridge, Cambridge University Press.

Soete, Luc. 1985. “International diffusion of technology, industrial development and technological leapfrogging”, in *World Development* (Washington, DC), Vol. 13, No. 3, pp. 409-422.