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Published in:
Journal of Information Science

Publication date:
2003

[Link to publication in Tilburg University Research Portal](#)

Citation for published version (APA):
James, M. J. (2003). Free software and the digital divide: Opportunities and constraints for developing countries. *Journal of Information Science*, 29(1), 25-33.

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Journal of Information Science

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Journal of Information Science 2003; 29; 25

DOI: 10.1177/016555150302900103

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Free software and the digital divide: opportunities and constraints for developing countries

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Received 11 July 2002

Revised 30 September 2002

Abstract.

Our focus in this paper is mainly on the GNU/LINUX operating system and the advantages that it affords developing countries seeking to bridge the global digital divide. In the early parts of the paper we argue that, although GNU/LINUX can generate substantial savings when used instead of the proprietary alternative in numerous institutional settings, the most telling opportunities for developing countries arise when this system is combined with other ways of reducing computing costs. Policy, therefore, should not only consist of substituting GNU/LINUX for proprietary software in running the latest and most expensive hardware, but also of lowering these latter costs themselves. Later sections focus on the link between the choice of software and path-dependency (i.e. the notion that if one system gets ahead, it tends to lock out alternatives in the manner described by Brian Arthur). We suggest that the problem of proprietary lock-in in developing countries has been greatly accentuated by piracy of Microsoft operating systems and that the result is a stagnation of the technological capabilities in software that these countries need so badly.

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1. Introduction

Although there are other ways of gaining access to the Internet than by computers (the most prominent of which is perhaps a cable set-top box using a television and a special keyboard) [1], it is on the former that users overwhelmingly continue to rely in order to connect themselves (via one or other form of telecommunications) to the World Wide Web. To this extent, therefore, the issue of computer access needs to feature prominently in any attempt by developing countries to overcome the huge digital divide that separates them from the rich countries (as of course do other constraints such as infrastructure). Also, in a context where the price of a modern computer in the developed countries is affordable by only a small minority in the Third World, this means inevitably that one needs to focus heavily on all available means of reducing the costs of operating these products [2].

Partly because of the difficulty of dealing with so large a focus in a single paper and partly because it seems so obviously relevant to the task of effecting a reduction in computing costs, this paper will concentrate below on just one such policy tool, namely free, as distinct from proprietary, software. Following a brief description of this type of software, the opportunities it affords are examined, as well as the constraints that need to be overcome if the opportunities thus identified are actually to be realized. The focus is mainly on the GNU/Linux operating system because it has an especially direct link to efforts to bridge the global digital divide and because it can be related to the debate over path dependency in the choice of operating systems.

2. Free software, GNU/Linux and proprietary software

Free software (free software is similar to but different from open-source software; for a definition of the latter see www.opensource.org) is perhaps most authoritatively defined as a matter of the user's freedom to run, copy, distribute, study, change and improve the software. More precisely, it refers to four kinds of freedom, for the users of the software:

- the freedom to run the program, for any purpose;
- the freedom to study how the program works and adapt it to one's needs; access to the source code is a precondition for this;
- the freedom to redistribute copies so one can help one's neighbour;
- the freedom to improve the program, and release improvements to the public, so that the whole community benefits; access to the source code is a precondition for this (www.fsf.org/philosophy/free-sw.html).

Over time a process of continuous change ensues, as each modification of the source code is made publicly available and subsequently improved upon. As exemplified most clearly by the Windows operating system, in contrast, 'Proprietary software is software that is not free or semi-free. Its use, redistribution or modification is prohibited, or requires you to ask for permission, or is restricted so much that you effectively can't do it freely'.

The free software movement has a large number of successful applications to its credit, such as Apache in the area of server-type software, and Perl in the sphere of computer languages (the former, in fact, has, since 1996 been the top web server). Although the Linux operating system is often referred to as another of the important achievements of the free software movement, the correct term is GNU/Linux, since the system is a combination of, among other things, the GNU project begun in 1984 to create a free version of the UNIX operating system (where free was defined as software that can be freely used, read, modified and redistributed) and the operating system kernel Linux Torvalds began developing in 1991.

As noted above, attention will be focused on the GNU/Linux operating system and more specifically on the application of this system to low-income users of computers in developing countries, many of whom may be first-time operators and whose ability to close the digital divide is the major concern of this paper. (This is not to suggest, however, that GNU/Linux conveys no benefits to other parties in developing countries. Indeed, system administrators benefit from the function

of GNU/Linux as a web server operating system. According to two Netcraft surveys conducted in 2001, it is the second most popular product in this category, with a market share of around 29% [3].)

Let us then consider the opportunities afforded by free software in general and GNU/Linux in particular, for expanding access to computer use by means of reducing their costs. Such opportunities, as was suggested earlier, are crucial to any attempts to spread the Internet more widely in those countries (and especially in Africa where there are reported to be fewer than three computers per 1000 people). The main conclusion is that, because discussions about software cannot be separated from issues relating to hardware, the focus inevitably becomes the broader one of low-cost computing in developing countries.

3. Opportunities

The main point to be emphasized in this section is that, although free software on its own can generate substantial savings, when used instead of the proprietary alternative in institutional settings such as schools or government agencies, the most telling opportunities for developing countries arise when this type of software is *combined* with *other* ways of reducing computing costs. The goal of policy, that is to say, should not simply be to substitute open-source for proprietary software in running the most modern (and expensive) forms of computer hardware, but rather to alter the costs of the latter as well, in one way or another. In fact, it is useful to divide these more extended possibilities into three main categories, the first involving the inclusion of free software in new computer models designed specifically for ultra low-cost use and the second involving the fact that non-proprietary forms of software can often be run on relatively outdated versions of computer hardware (note, in this regard that GNU/Linux was designed originally for computers running the 386 processor). The third possibility involves the implications of the choice of software for user capabilities and the chance to adapt free software to local conditions at some future point.

3.1. Free software embodied in new low-cost computer hardware

Table 1 lists three computers that are already, or will soon be, available on the market for as little as \$200–300. The first two innovations, the 'Simputer' and the 'Volkscomputer' were designed specifically for the

Table 1.
New Low-cost computers embodying free software

Name of innovation	Innovator	Location	Price	Software
Simputer	C-Dot (semi-autonomous government institution), www.cdor.com	India	\$200	Based on Linux
People's computer	Federal University of Minas Gerais, www.luar.dcc.ufmg	Brazil	\$300	Based on public domain software
New Internet Computer	Oracle Corp., www.oracle.com	USA	\$200	Linux

Indian and Brazilian markets, respectively, while the 'New Internet Computer' was developed in the United States for users needing only e-mail and Internet access (as in the case of the Brazilian 'Volkscomputer', the New Internet Computer lacks a hard disk drive and is said to be targeted at consumers, small businesses and schools). In each of the three cases, the exceptionally low price of the product is due partly to the use of free as distinct from proprietary software, but it is partly due to other factors as well. It has already been mentioned, for example, that the last two examples economize on costs by designing the product exclusively for Internet access, thus obviating the need for a hard drive. In the Brazilian case, moreover, the computer chip and modem, although adequate to the task at hand, are said to be relatively dated and hence relatively inexpensive. As far as the Simputer is concerned, part of the low selling price is also due to the fact that its electronic components are purchased in volume 'off the shelf'. (For further information on the specifications of the Indian and Brazilian low-cost computers see the Appendix to this paper.)

The potential of the Simputer to bring computers to the low-income masses (the group on which this article is focused) has been very succinctly stated in a recent commentary which is well worth citing. In particular, it described the Simputer as a small 'hand-held device designed for the rough conditions of rural India'. It operates – without a keyboard – through touch, sound and simple visual icons. It translates English-language web sites into local Indian languages, reading the content aloud to illiterate users.

The Simputer is expected to cost 9000 rupees, or about \$190; it is meant to be owned not by individual users but by village cooperatives. Each user carries a simple, tough, very cheap 'smart card', which will hold all his or her settings and data. No training is required; there are no upgrades, no broadband and no planned obsolescence. It runs on batteries.

This is 'computing as it would have looked if Gandhi had invented it' [4].

3.2. Free software and the use of early generations of computer hardware

Viewed over time a major problem with proprietary software, in the context of developing countries, is that it tends to lock users into a pattern of ever more sophisticated forms of software and a corresponding need for ever more powerful and expensive hardware. Such 'path dependency', with which so-called premature obsolescence is often said to be associated, arises most starkly in the USA, where according to an article published in 2000, 'Over the last three years 62 million computers were "rendered obsolete" in terms of their ability to run standard software'. And the source of this 'epidemic of functionally obsolete computers' lies not 'in the machines themselves which were all built with an average functional lifespan of at least eleven years, but [instead] with the software industry. *Newer faster software continuously demands newer faster computers*' (emphasis added) [5].

For developing countries seeking to lower computing costs and widen access to the Internet, perhaps the major advantage of free software is its ability to prevent, and indeed reverse, the costly spiral described in the previous paragraph (see below in section on path dependency). This opportunity arises out of the fact that free software such as GNU/Linux can be run on relatively dated computers such as those based on the 486 processor (although not *any* Linux distribution will have this capability or will run well enough to be useful). That the joint savings from free software and low-cost hardware can be substantial was already recognized by some educational institutions in developing countries even in the 1990s. In 1999 it was said of the Philippines, for example, that

A number of local schools are discovering that Linux can save them from inevitably increasing their tuition fees every time they have to upgrade their computer systems. Educators who discussed the advantages of Linux in schools . . . agreed that this free open-source operating system that can run on low-end machines can

free them from the financial bounds of commercial software distribution and upgrades [6].

Similarly, in 1998 the Mexican government announced that it was planning to install GNU/Linux in 140,000 elementary and mid-level schools across the country, and subsequent reports suggested that the resulting savings in Microsoft licenses could have amounted to as much as \$3 million [7]. To this amount one should add the savings arising from the compatibility of GNU/Linux with the older, less expensive computer hardware that was in use at the time (as opposed to having continually to upgrade this hardware to meet the needs of the alternative, proprietary software). Unfortunately, however, the program has thus far failed to meet its ambitious goals, mainly because of a scarcity of staff who are familiar with GNU/Linux (see also Section 4.3).

Even in developed countries, where the cost constraints on computer usage are generally much less acute, the advantages afforded by the combination of free software and inexpensive hardware have not gone unnoticed. The reason is partly that even the richest countries are confronted with an internal digital divide separating the relatively affluent, educated groups with access to computers and the Internet from less privileged members of society who do not. In order to bridge this divide, free software is one attractive policy option. The Computerbank Australia, for example, aims 'to collect and then redistribute older donated hardware to people who can't otherwise afford the costs associated with computing' [8]. It should be emphasized that for such people the choice is not between free software and proprietary software, but rather whether they can compute at all.

3.3. Free software, user capabilities and local adaptations

Technological capabilities (as applied to both users and producers) have rightly been emphasized in the development literature as being crucial not only to the effective use of imported capital goods, but also to the adaptation of such goods to local conditions [9]. After all, the industrial histories of many developing countries (especially but not only in Sub-Saharan Africa), are replete with examples of investment projects that failed because of the lack of local user capabilities and imported technologies that were totally unsuited to domestic factors such as market size, complementary inputs and so on. Such problems as these arise mainly from the fact that most technical innovations occur in,

and for, developed countries and tend accordingly to be poorly suited to the socio-economic circumstances prevailing in the Third World. In the absence of a deliberate policy effort, developing countries can thus easily find themselves caught in a dangerous circle, whereby the lack of local capabilities fosters technological dependence, while the latter itself perpetuates the former (Sub-Saharan Africa is a region that well illustrates this particular problem). Obviously, many policy issues arise in considering how to break this vicious circle most effectively. It is not the intention here to review this complex debate, ranging as it does across a large number of developing regions. One point, however, bears emphasis in the present context and that is that the acquisition of many forms of technological capabilities requires a process of learning-by-doing (even though in the short run this may be accompanied by the costs of inefficiency and inexperience).

Let us now apply the general arguments advanced in the previous paragraph to the particular choice between proprietary and free software in developing countries. Whereas the former would seem – almost by its very definition – to lock users into a classic pattern of dependency on large multinational corporations and a corresponding stagnation of indigenous software capabilities, the latter 'lends itself to be adapted to diverse languages and applications by ... programmers, working for local organisations and the government' [10]. Free software can also have 'a positive multiplier effect in the sense of encouraging the programmer community to explore and experiment with developing applications. As the barriers to entry in the case of proprietary software (high cost, poor availability, lack of online documentation and lack of source code) do not apply to free software, freedom of experimentation is very high' [10].

Such tinkering, we would suggest, is closely analogous to the historical and contemporary role of reverse engineering in promoting the acquisition of indigenous technological capabilities in developing countries. When it is added to the other opportunities associated with free software that have been described above (note, however, that proprietary software, as a computer operating system, contains more applications than systems such as GNU/Linux), one is immediately led to ask why such software is not more widely used for basic applications in developing countries (especially those that are concerned to overcome the digital divide with the rich industrialized regions of the world). Even in relatively developed parts of the Third World, for example, such as Latin America, where GNU/Linux use is growing relatively rapidly, projec-

Table 2.
Top 25 countries by piracy rate

	1999	2000
Vietnam	98%	97%
China	91%	94%
Indonesia	85%	89%
Ukraine/Other CIS	90%	89%
Russia	89%	88%
Lebanon	88%	83%
Pakistan	83%	83%
Bolivia	85%	81%
Qatar	80%	81%
Bahrain	82%	80%
Kuwait	81%	80%
Thailand	81%	79%
El Salvador	83%	79%
Nicaragua	80%	78%
Oman	88%	78%
Bulgaria	80%	78%
Romania	81%	77%
Guatemala	80%	77%
Paraguay	83%	76%
Jordan	75%	71%
Honduras	75%	68%
Costa Rica	71%	68%
Dominican Republic	72%	68%
Kenya	67%	67%
Nigeria	68%	67%

Source: BSA (2001) [12].

Note: These percentages may in some cases have altered substantially since the dates in the table.

tions indicate that only 33% of computers in the region will be running Linux by 2003 [11]. Let us turn therefore to the constraints that confront attempts to replace proprietary with free software such as GNU/Linux.

4. Constraints

4.1. Piracy

Arguably the most important constraint facing the free movement in developing countries has a somewhat paradoxical quality. For what has to be confronted is not so much the heavy marketing and advertising campaigns of companies such as Microsoft, as the fact that the piracy rates of products such as Windows are so remarkably high (Table 2 in fact shows that the highest piracy rates are mostly to be found in developing countries and to a lesser extent the transitional economies of Eastern Europe). As a result, the *potential* cost advantage offered by free software systems

described above is in fact for the most part non-existent or minimal in such countries and pirated software dominates the market at the expense of both the original proprietary versions and the legally free systems such as GNU/Linux (which are not as well known and which require a certain degree of initial technological capability).

A report that appeared in 2001 on the situation in Africa, for example, refers to an entrenched disrespect for copyright laws that continue to protect proprietary software. With the use of unpaid-for Windows software rampant in some areas, what motivation is there to switch to another system? This is where the battles in the software industry will be held. Open-source advocates believe that, when African governments start viewing a deeper usage of technology as a higher priority than it currently has, they will decide to ditch proprietary software in favour of open-source software.

According to Mike Jensen, the author of the Africa Connectivity Report, this is already happening in countries like Mauritius and Senegal, where the governments have shown leadership in the adoption of Linux. Indeed, Jensen cites the lack of this leadership by African governments as an obstacle to the adoption of Linux.

'The main barriers to further use will be leadership', Jensen said. 'Only when the people at the top tell those down below they should use Linux rather than pirate will word go out' [13]. The ease of piracy is stopping many people from actively considering Linux for cost reasons.

Two related decisions by governments would thus seem to be crucial in determining the usage of free software in developing countries. One is the attitude towards, or stance adopted by governments towards, software piracy (although, of course, this stance is often itself a function of the pressure exerted by developed country institutions against this form of violation of intellectual property rights). In general, the tougher the stance taken against piracy by developing country governments, the more free software will tend to become a serious competitor to its proprietary competitors. The second issue then becomes one of deciding which of these competing forms will be chosen for use in government institutions such as schools, agencies and health services.

Latin America represents perhaps the clearest example of a region where the net effect of these factors has been to favour free software, especially in a number of the largest countries. Brazil, Argentina and Mexico, in particular, contribute by far the most retail software revenue lost to piracy in that region (see Table 3 for data

pertaining to the year 2000). On the one hand, despite a general acceptance of software piracy in Latin America, some of the larger countries in the region have begun, for one reason or another, to enact and enforce laws against this form of violation of intellectual property rights (as is the case most obviously with China and the World Trade Organization). In Brazil, for instance, lobbying by American corporations is forcing firms to reconsider their options in favour of legal operating systems (as opposed to the illegal use of proprietary software which carries the risk of steep fines or even imprisonment). In Argentina it was entirely legal to copy proprietary software until 'the country's intellectual property law was modified in November 1998 . . . Today, anyone caught with pirated goods faces fines and up to six years in the slammer' [14]. Outside Latin America, China is the most notable example of a country engaged in tightening and enforcing its laws on intellectual property in general and software piracy in particular. Where once pirated software was the norm, China has agreed, as part of her admission to the World Trade Organization, to redress this problem in government and business on a widespread basis [15].

Insofar as there has been a move to prohibit software piracy in a number of large developing countries, users are then confronted with the choice between free software on the one hand and regular proprietary versions on the other. Albeit sometimes for somewhat different reasons, some of the countries mentioned in the previous paragraph have on occasion tended to opt for the former over the latter. Mexico, for example plans to install GNU/Linux in 140,000 elementary and mid-level schools across the country.

To some degree, of course, decisions in favour of free software are made on cost grounds; the savings on licences for proprietary software operating systems can amount to thousands of dollars a month. The Mexican decision to use GNU/Linux in schools, for example,

was influenced by the savings that could be used to fight poverty. Cost issues, however, account for only part of the observed shift towards Linux in at least some parts of the Third World (and in any case the cost of software needs to be assessed alongside various 'hidden costs' and disadvantages for particular users who may require more applications, although such users are probably not very prevalent among the low-income, uneducated groups with whom we are here largely concerned). Other reasons have more to do with the role of this type of software in the acquisition of indigenous technological capabilities as described above.

If it is technological learning that partly underlies the choice of free software, it is in schools and universities that the process should ideally begin. According to a number of experts on the topic, students educated on GNU/Linux software will be better able to adapt rapidly to new platforms and applications, precisely because 'they have grown up with a system which encourages them to learn the underlying concepts of computing'. Indeed, in 1999 a report prepared by the National Research Council's Committee on Information Technology in the United States concluded that 'the employers' gains from receiving Windows-trained students was short-lived. The reason it gave was that Microsoft frequently introduces new versions with additional features and altered procedures as a way of building in obsolescence. The Committee recommends that, rather than seeking to turn out Windows users, colleges and universities should equip graduates with a deeper conceptual understanding to enable them to benefit from new technologies' [16].

4.2. Awareness

In the last few paragraphs it has been implicitly assumed that institutions make an explicit choice between two known options, namely, proprietary vs free software. Yet, in reality there is often an information bias that strongly favours the former over the latter in developing (and to some degree also in developed) countries, leaving a general impression that Windows is the only available operating system (even in certain advanced computer classes in the UK, Linux does not get mentioned). This impression is only reinforced by the pre-installation of this system in many new computers. This bias is partly the inevitable outcome of a situation in which original or pirated versions of proprietary software have totally dominated markets in developing countries over relatively long periods of time. In part, the information asymmetry is due also to the contrast between Microsoft with its vast promotional

Table 3.
Retail software revenue lost to piracy, 2000 in Latin America

Country	Lost revenue, '000s US dollars	Percentage of total for all Latin America
Argentina	114,403	13%
Brazil	325,617	37%
Mexico	180,164	21%
Total for all Latin America	869,777	71%

Source: Business Software Alliance, 2001.

expenditures on the Windows system and GNU/ Linux which is associated, by contrast, with individual donors and certain grant-giving institutions.

It is small wonder, then, that extensive and persuasive information campaigns will need to be mounted if one is to begin to redress the existing imbalance in the awareness of non-proprietary, as against proprietary, forms of software. A number of cases have already been mentioned where government institutions (especially, but not only in Latin America) have effectively performed this function. In other examples, however, it is private firms that have assumed the role of informing potential users about, and promoting the use of, the free software movement in developing countries.

One of the most interesting such examples is to be found in Kenya – a country not readily associated with free software – where a local firm called ‘Silicon Bazaar’ has undertaken the following activities on behalf of free software, to:

- (1) Use . . . [its] facilities to give free technology seminars every Thursday and thus create a technology community that is totally immersed in Free software.
- (2) Seed Kenya’s elite (academically) high schools with Free software.
- (3) Sell Free software at minimal cost.
- (4) Provide Free software training also at minimal cost.
- (5) Cajole our universities into using Free software for student instructions.
- (6) Partner with any company that wants to rid itself of proprietary software.
- (7) Donate free website hosting to the previously mentioned high schools (personal, communication from Mr. Githogori Nyangara-Murage of Silicon Bazaar, 31 January 2002).

Of these various promotional activities, the free weekly seminars are apparently the most successful, and continue to attract interested parties several years after the inception of the programme.

Advocacy of free software is being pursued with no less zeal by ‘FreeOS.com’, a resource centre for free operating systems based in India. Unlike the Kenyan firm whose promotional activities have just been described, ‘FreeOS.com’, as its name suggests, relies heavily on its own web site, where ‘One can find information, articles, documentation, downloads, news, links – essentially anything related to all Free Operating Systems’ [17].

4.3. Path dependency

Much of what was described in the previous section can be combined under the single heading of ‘path dependency’, a tendency that, as described by Arthur [18] is caused by increasing returns:

Increasing returns are the tendency for that which is ahead to get farther ahead, for that which loses advantage to lose further advantage. They are mechanisms of positive feedback that operate – within markets, business, and industries – to reinforce that which gains success or aggravates that which suffers loss. Increasing returns generate not equilibrium but instability: if a product or a company or a technology . . . gets ahead by chance or clever strategy, increasing returns can magnify this advantage, and the product or company or technology can go on to lock in the market [19].

In the technological context, increasing returns, as just defined, can arise from a number of different sources. Often, for example,

the more a technology is adopted, the more it is used and the more is learned about it; therefore the more it is developed and improved . . . Often a technology offers advantages to ‘going along’ with other adopters of it – to belonging to a network of users . . . Often a technology that is more adopted enjoys the advantage of being better known and better understood . . . Often, as a technology becomes more adopted, a number of other sub-technologies and products become part of its infrastructure . . . This puts it at an advantage in the sense that other technologies, if less adopted, may lack the requisite infrastructure or may require a partial dismantling of the more widespread technology’s in-place infrastructure [19].

Given the concern in this paper with the choice between free software in the form of GNU/Linux and Microsoft Windows, it is telling that, in Arthur’s view, operating systems exhibit increasing returns of the kind that have just been described. ‘If one system gets ahead, it attracts further software developers and hardware manufacturers to adopt it, which helps it get further ahead’ [18]. Unfortunately, the system that dominates locks in the market as described above.

In the specific context of Microsoft use in developing countries we should note, first, that such advantages as may have accrued from the workings of the increasing returns listed above have been hugely and artificially accentuated by the prevalence of pirated software in those countries (as distinct from developed countries where piracy occurs to a much lesser degree). So one can describe part (perhaps a large part) of the lack of familiarity with free software in developing countries as being artificially induced, above and beyond what one might have expected from the ‘usual’ workings of path dependency. The repercussions of this amplified effect, it is suggested, go much further than the lack of (or limited) choice confronting the software user. Perhaps most seriously, what usually occurs is a stagnation of

the technological capabilities of the software industry as a whole. For, on the one hand, by its very nature, proprietary software provides limited learning capacity as noted above, and on the other hand, the call for, and supply of, free software is heavily obstructed. For both reasons, the scope for indigenous technological advancement becomes well-nigh negligible. In the Mexican schools project noted above, for example, the main problem proved to be the lack of people trained in the GNU/Linux operating system, and other school projects in developing countries may well have encountered the same problem.

Technological interventions to counteract the effects of path dependency would thus seem to be inevitable in most developing countries. National governments will need to bear the brunt of such efforts, through, for example, the establishment of research centres devoted to local applications of free software, the training of computer professionals in GNU/Linux and the dissemination of this software among government schools. There is, however, also much that can be done by foreign aid agencies and NGOs (UNESCO, for example, maintains a Free Software Portal).

5. Conclusions

Perhaps the single most important problem in increasing the extent of access to the Internet in developing countries is that the costs of such an endeavour are usually prohibitively high. The underlying cause of this problem, in turn, is that innovations in information technology, as in other areas, tend to be based on incomes in developed rather than developing countries where there is a need for lower cost basic access, rather than, say, better services, more accessories and higher bandwidth. If the digital divide between rich and poor countries is to be lessened, therefore, it would seem inevitable that the costs of spreading access in the latter need to be drastically reduced.

The goal in this paper, however, has not been to address all the complicated issues that such an endeavour would entail, involving not only different forms of information technology but also a variety of different organizational factors. The purpose, rather, is to focus on only one aspect of this larger problem, namely, the opportunities and constraints afforded by free, as opposed to proprietary, forms of software (such as Microsoft Windows). To many people this may at first seem like an unduly restrictive focus, which is at best marginal to the debate as a whole.

As the first part of the paper sought to show, however, this is an erroneous perception that needs to be altered, most importantly in the eyes of policy-makers seeking to overcome the digital divide between rich and poor countries. What needs to be recognized first is that it is technically possible (in an engineering sense) to combine free software with low-cost hardware designs to produce a computer that sells for as little as US\$200 (as shown in Table 1). What also needs to be recognized is that free software affects the price of computer hardware by avoiding the path dependency cycle of ever more sophisticated software being driven by increasingly powerful hardware that is so closely associated with the dominant sellers of proprietary software. In this pattern, newer faster software continuously demands newer faster computers. Free software, by contrast, offers developing countries the opportunity to prevent and indeed even reverse this costly spiral, because it can be run on relatively dated computers such as those based on the 486 processor. The joint savings from free software and low-cost hardware can be substantial when they are aggregated over a large number of computers in, say, all the schools in a single region of a developing country (as illustrated by the figures cited in the first part of the paper). Put another way, many more students gain access to computers with a given budget. Finally, it is essential to recognize that today's choice of operating software also affects a developing country's future technological capabilities and in particular its capability to design computers that are relevant to the needs of poor rather than rich countries through a variety of mechanisms that are associated with path dependency. From this important point of view, free software also appears more promising than proprietary versions as the former, unlike the latter, encourages the programmer community in a country to explore and experiment with new applications. Such tinkering, it is suggested, is closely related to the historical role of reverse engineering in promoting indigenous technological capabilities in some of the now developed countries.

The second part of the paper addressed itself to the question of why, in spite of these clear advantages, free software is not widely used in most developing countries. Part of the problem seems to be the high piracy rates of proprietary software in most such countries, which nullify the cost advantage of free software such as Linux (indeed, in several such countries piracy rates exceed 80%). It was found, nevertheless, that there are examples of large developing countries which have not only taken a series of measures to combat piracy, but which have also selected free software to fill the result-

ing gap (in schools and public sector institutions). Even in the absence of piracy, however, free software such as GNU/Linux seems to be unfamiliar to large numbers of potential users who, partly because of the mechanisms underlying path dependency, tend to think of Microsoft Windows as the only available operating system (not least, it is argued, because this latter system is often pre-installed on many new computers). For this and other factors associated with path dependency, countervailing information is clearly required and, together with other support such as training, should be supplied by international organizations (such as UNESCO and the UNDP), national governments (as for example in Mexico), free software research institutes and training for computer professionals.

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Appendix: Specifications for the Indian Simputer and the Brazilian People's Computer

A.1. The Simputer specification

- Intel's 32-bit Strong Arm SA-1100 RISC CPU running at 200 MHz.
- 32 MB of DRAM, 24MB flash memory for storage.
- 320-240 monochrome liquid crystal display.
- Touch-panel for pen-based computing.
- Speaker and MIC jacks, smartcard connector
- RJ-11 telephone jack.
- USB connector.
- Power supply three AAA-sized NiMh batteries.
- Based on Linux operating system.
- $8 \times 13 \times 2$ cm.

A.2. PC Popular specification

- CPU: AMD K6II-500 (Pentium 500 MHz).
- 64 Mbytes RAM and 16 MB flash disk.
- Ethernet network adaptor.
- 56 Kbps modem.
- Sound, mouse, 14 inch monitor, keyboard.
- USB port.
- Based on public domain software: Linux with X Windows/KDE; Konqueror browser; KOffice.

Source: Jensen (2001), New low cost computers from India and Brazil: the potential for Africa, *RINAF Workshop*, UNESCO/GNICIC (27–28 September, Accra, Ghana).