Information and Communication Technologies' role in productivity changes, rebound effect and sustainable consumption

Andrius Plepys, research associate
The International Institute of Industrial Environmental Economics at Lund University
P.O.Box 196
Tegnersplatsen 4
SE-221 00, Lund, Sweden
Tel: +46-46-222 02 00
fax: +46-46-222 02 30
e-mail: andrius.plepys@iiiee.lu.se

Abstract

Information and Communication Technologies (ICT) sector takes a leading role in the new Economy experiencing unprecedented growth rate. How does it mean for sustainable development?

The article discusses the problem of rebound effect analysing the role of ICT sector in productivity changes and potential environmental impacts. The author discusses known origins of the rebound effect as well as presents subjects for on-going debates. A variety of problems are revealed in the article: Is there a proof that ICT sector causes rebound effect? Do we know the rebound effects on macro level pertaining to other sectors of economy? What issues should become a top priority when making policy decisions in ICT sector?

Keywords:

ICT, rebound effect, consumption, efficiency and productivity.

Introduction

In 1949 the Popular Mechanics magazine wrote "…computers in the future may weigh no more than 1.5 tons" and the chairman of IBM added that there might be a market for only five computers worldwide. After fifty years there are hundreds of millions of computers worldwide connected into huge parallel world of cyberspace. A completely new economy sector of Information and Communication Technologies (ICT) has emerged forming a core for New Economy – an economy based on dynamism, information openness, unlimited communication capabilities and huge investments into high-tech sectors. The ICT sector emerged as something completely different from traditional material and energy intensive economic sectors – a sector that relies on knowledge and technological innovation, things the economic boom of the late 90s is associated with.

The R&D advancements allowed unprecedented growth of the sector and electronics has quickly penetrated into our everyday lives restructuring economy worldwide. Major system-level changes (often referred as *structural changes*) in infrastructure, institutional arrangements, technological capabilities, and lifestyles are under way. All these changes eventually have certain impacts on the environment.

Traditionally the ICT sector has been perceived as environmentally clean, mainly handling information instead of kilograms and megawatts. In the 90's several studies have shown that (at least in USA) there are decoupling trends between economic growth and the use of natural resources. Much of this is associated with the New Economy and ICT sector in particular. At the same time there are concerns over increased consumption of electronic products leading to first and second order negative environmental impacts. At the first place growing amounts of electronic waste increasingly becomes a serious problem worldwide. Secondly, the ICT provides us with a possibility to do things faster and more efficiently increasing both - our economic prosperity and material throughput.

The unprecedented economic growth at the turn of the century resulted in absolute increase of natural resource consumption, threatening to compromise the sustainable development efforts. The concerns about the so-called backfire or *rebound effects* emerged in the early 80s in utility sectors during the Middle-East energy crisis. Today, the same concerns emerge around the negative effect of growing consumption in ICT sector. There are less kilograms and watts tied up in computers, but there are more computers and the inherent toxicity of waste increasingly becomes a serious of environmental problem.

Nevertheless, ICT sector has big potential for dematerialisation – providing functionality without increasing natural resource consumption.

While industries and retail sector are less interested in curbing product consumption, government actions can be directed to encourage less material intensive ICT businesses. Policy makers must be given clear signals about the threats and opportunities posed by rapid evolution of ICT products and services in order to utilise appropriate instruments that would facilitate optimal sector development based on innovation and sustainability principles.

Sustainable consumption is likely to be one of the major issues for sustainable development, but a number of uncertainties exist on the way. First of all, the impact of ICT sector on resource conservation is still largely unknown. Second, there are serious debates about the role of the ICT sector in productivity growth in the whole economy. This is important to know for decision-makers to set the right priorities in resource conservation efforts.

This paper focuses on potential rebound effects caused by different developments in the ICT sector. The scope includes the effects within the sector and attempt to capture its link to the other sectors of economy. Several aspects of current debates around the ICT role in productivity growth are presented for this reason. A discussion is formed about the role of policy-makers in addressing the environmental problems caused by growing use of electronics.

Rebound effect and the ICT sector

Environmental protection activities have been gradually developing encompassing several approaches such as end-of-pipe in 60's and 70's, pollution prevention and sustainable development in 80's - 90's. Efficiency improvement strategies appeared on agendas of many international organisations such as UN, OECD and WCED.[1] Over the last decade a number of sustainable development concepts and approaches have been introduced advocating eco-efficiency as a tool for resource conservation.

However, the eco-efficiency concept may fail addressing growing consumption problems. A more efficient use of natural resources does not always lead to resource conservation on the long run. Efficiency improvements make resources more abundant increasing their supply with corresponding decrease in final price and increasing consumption due to changes in consumer behaviour. The phenomenon, common for energy utilities, is called *rebound effect* and is an unintended side effect of efficiency improvements, which in fact might reduce or negate resource conservation efforts.

The first systematic analysis of the rebound effects was done already in the late 70s' by energy economists, who stated that increased energy efficiency will result in higher energy consumption. The majority of studies focused on energy consumption for heating and

[1] WCED - World Commission on Environment and Development.

transportation in single economy sectors, but later the focus gradually moved to economy-wide effects in other sectors of economy.[2]

A series of debates around eco-efficiency and rebound effect evolved throughout 80s and 90s.[3] The debate questioned the effectiveness of efficiency improvements as a tool achieving sustainable development through natural resource conservation and increasing the standard of living. The rebound effect researchers conclude that increased demand for a product or service without subsequent increase in its price can erode technological (or any other) efficiency gains [27], [15], [16]. However, it seems that there is still no consensus about the significance of the rebound effect and many studies show that it differs from sector to sector.

Energy economists generally acknowledge the existence of rebound effect, but disagree on its significance, which seems to be different in different sectors of economy. Depending of the definition of rebound effect and thus the scope of analysis the size of the rebound effect can be different insignificant or offsetting the resource savings from efficiency improvements [16].

Typology of rebound effect

A uniform definition of rebound effect has not been established yet. Many equivalent terms, such as *growth* effect [42], *economic forces* (demand side effects) [18] or *take-back* effect [15] are in use. Normally the term *rebound effect* is used for a less than one-for-one correspondence between efficiency gains and reduced consumption. An extreme version of rebound effect, i.e. when efficiency gains are totally negated by the increased consumption is sometimes called *backfire effect* [45]. The rebound effect definition, formulated by energy economists in the 1980's as a side effect of increased consumption due to efficiency improvements, still dominates the literature.

The terminology proposed by (Greening, 2000) [16] after reviewing a large number of previous studies distinguished several types of rebound effects depending on the boundaries of focus. On micro-level of single industry branch the so-called *direct* rebound effects are distinguished. The effect is sometimes called *pure price effect* – the increase in resource use efficiency is followed by its price reduction causing a positive shift on demand curve.

---

[2] Early articles on the topic of rebound effect can be found in international magazines *The Energy Journal* and *Energy Policy*.

[3] E.g. A.B. Lovins and E. von Weizsäcker vs. D. Khazoom and L. Brookes.

This effect can be further subdivided into *substitution* and *income* effects. Theoretically, the increase of resource consumption is limited by available financial resources (e.g. income). However, in reality there is always a substitution potential among goods and services, therefore a consumer often does not maximise his/her demand for the "bargain" resource up to the income limit, but rather use some of the extra purchasing power for other goods. This results in increased consumption of other goods and services, which is called *indirect* or *secondary* rebound effects [16]. The indirect or secondary rebound effects (also called income effect) occur due to increased savings as a consequence of the direct rebound effect – a consumer has more financial means for consuming other products.

In market conditions the direct and secondary rebound effects cause supply/demand equilibrium shifts for other commodities. These effects are called *general equilibrium* or *economy-wide* effects [16]. At least theoretically they can be considerably larger than the effects on micro-level, but these effects are very complex and stochastic and this area deserves further studies.

The fourth typology of effects suggested by (Greening, 2000) [16] is *transformational* effects. They represent alterations in consumer's preferences, social institutions and organisation of production, which are induced by technology changes. Up to now there is no theory to predict these effects, because along with efficiency improvements there are also changes in allocation of time – an important factor for consumer behaviour.

How does rebound effect occur in ICT sector?

While the research on rebound effect in energy sector was quite substantial, very few studies addressed it in the ICT sector. The reason might be in a perception that the direct effects are virtually nil - we do not buy more computers, because they become more energy efficient.

Traditionally the rebound effect terminology is used to describe the impacts of efficiency improvements on consumption of different utilities (e.g. energy and water). Today computers have probably become also a utility in some way. Their role in global economy is increasingly perceived as general-purpose technology performing the role of an economy lubricant - similar to what steam engine have become. Computer are also utility-like commodities in economic sense – they are "consumed" within a limited time of up to 5 years, which is their economic life in businesses.

The pace of technological developments of ICT is spectacular and already for thirty years follows the famous Moore's Law.[4] The exponential performance improvements of electronics goes hand in hand with the reduction in cost per chip element, so that quality-adjusted computer price drops by 20-30% annually. Parallel improvements in software and growing computer connectivity increased computer functionality and reliability, which results in doubling the Internet traffic every 6-9 months. The communication costs worldwide have been constantly falling as a consequence of growing infrastructure, introduction of new technologies and market deregulation.

The combined result of falling computer and communication prices as well as global economic growth was that hardware sales over last decade have skyrocketed worldwide followed by similar trend in Internet service. A positive feedback loop emerged - falling costs hardware and services stimulate ICT penetration in all sectors of economy enhancing functional performance of traditional products.

During recent decades ICT sector attracted huge investments of risk capital supplying immense funds for research and development, which in turn further speeded up ICT development, reduced production costs and increased affordability. Higher demand gives positive signals to stock markets, which provides new investments into ICT sector. The result is a *rebound-like effect* – the increase of computer performance efficiency increases hardware consumption in the sector (**Figure 1**).

The effects of information technologies to economy and society are very complex, but they can be divided into two categories – effects on *micro-* and *macro-levels*. A micro-level rebound effect in this context will be an effect of increased consumption of information technologies (hardware, materials and energy utilities), which occurs only within ICT sector – the direct and secondary rebound effects according to (Greening, 2000) [16]. A macro-level rebound effect then is an effect, which relates to other sectors of economy, and which changes in people’s preferences, social institutions and organisation of production. In Greening’s typology that will be economy-wide and transitional rebound effects (see **Figure 2**).

[4] Gordon Moore - the founder of Intel Corporation in 1964 made a prediction, which is so far confirmed by the developments in microelectronic industry.

Consequences of direct rebound effects on micro level

Production stage

The ICT sector is traditionally associated with miniaturisation, lightweight and operating more with information than physical products. The material and energy intensity along the life cycle of electronic products is different. Certain life cycle stages, such as material extraction and chip manufacturing, involve particularly large material flows. Most of the flows are due to the use of rare compounds in electronics - the Wuppertal Institute in Germany has shown that a golden ring has an "ecological backpack" of material intensity equivalent to 10 tonnes. The "backpacks" of commonly used elements such as germanium, arsenic, indium, tantalum, etc. are usually large. A study performed by the same institute showed that manufacturing of one PC takes 2/3 of the weight of material needed to produce one car and this does not include materials to manufacture the car's electronics.

Manufacturing of semiconductors becomes increasingly energy and material-intensive, as advancements in semiconductor technologies continuously require the use new compounds based on rare compounds and synthetic materials. The acquisition of raw materials and synthesis are highly material-intensive processes producing huge quantities of mining waste. The improvements in semiconductors' performance are based on miniaturisation and diminishing concentrations of active compounds, which poses growing demand for material purity and requires large amounts of energy.

Even though the concentrations have a tendency to reduce, material toxicity is still unsolved problem. In 1993 about half of the 700 different chemicals used by the computer industry in the US were hazardous [9]. Manufacturing semiconductors, printed wiring boards and cathode ray tubes (CRT) is associated with largest material consumption and waste generation. A typical computer monitor with a CRT contains 1-2 kg of lead and out of 54 most used chemicals in silicon chips, electronic circuits and monitors, 15 are known or suspected carcinogens and 14 are heavy metals [10].

According to 1995 data from Silicon Valley Toxics Coalition the production of a 6-inch wafer requires 8.6 m^3 deionised water, 9 kg hazardous chemicals and 285 kWh electricity [47]. According to (Mills, 1999) [35], it takes about 60kWh to etch circuits on a 6-inch silicon wafer, so as a result the energy consumption to produce single PC is about as much as it will be consumed during its lifetime. Another study provides numbers of the same order of magnitude. The production of a 8-inch chip used for Pentium CPUs requires 11.44 m^3 of deionised (super-clean) water, 120.8 m^3 of bulk gases, 12 kg chemicals and produces 0.82 m^3 hazardous gases, 14 m^3 waste water and 4 kg hazardous waste [1].

The material consumption for ICT infrastructure (communication lines, routers, amplifiers, servers, filters and buildings) is also significant. As more computers are bought every year, the net material and energy consumption might outweigh the efficiency improvements in hardware production and performance.

Use stage

A few studies suggest that energy consumption is a larger problem than material consumption in the life cycle of electronics. An Ecological Footprint methodology applied in a study by (Frey, 1999) [12] on personal computers showed that a PC had a footprint of 1,800 m^2, where the footprint of energy use turned out to be 1,000 times larger than the footprint for resource consumption during entire life cycle. The second major energy consumption has been determined to be in material production stage.

The study acknowledged that the total footprint would have been even larger if the production of precious metals such as gold, silver and beryllium would be taken into account. The footprint of water consumed, which can be up to 74 m^3 over the entire life cycle of a PC, was not accounted too. Nevertheless, the final conclusion was that that the ecological footprint of a PC is almost exclusively determined by fossil fuel use.

Another life cycle assessment study of a generic personal computer performed for EU eco-labelling scheme showed that the user phase has largest environmental impacts in all analysed impact categories [22]. The impacts from this phase are almost totally related to the use of energy.[5] The manufacturing and material production turned out to be next most important stages with 4-6 times lower environmental impacts (Figure 3). The energy consumption in material extraction and manufacturing is smaller than in user phase by 10 and 4 times respectively.[6]

Several extensive LCA studies have been performed by NEC Corporation, which during 1997-99 conducted LCA analysis of around thirty categories of products and electronic components. A result from the study on desktop computers and laptops has shown that the use phase has major part of global warming impacts of the whole life cycle.

---

[5] See Appendix, Table 1.

[6] See Appendix, Table 2.

The examples like these indicate that potential direct rebound effects from ICT sector growth will most likely be in energy consumption in the use phase of ICT products. Nevertheless, given the complexity of production and consumption chains and the share size of the sector itself, other potentially larger rebound effects in the production stage can be easily overlooked. More studies are needed regarding both energy and material consumption. Material consumption is particularly difficult to account, because of the global nature of hardware production.

End-of-life stage

The negative environmental effects of growing consumption of electronic hardware are most visible in the end-of-life stage. During the 90's a number of studies have been looking into end-of-life management of electronic waste and particularly computers. According to some estimates, there are 14-20 million computers scrapped yearly, around 10-15% of them re-used or recycled, 15% end up in landfills and the rest are stockpiled by users [13]. According to a model developed at Carnegie Mellon University, only in USA alone, which has a 15% market growth rate and 30% of worldwide computer sales, nearly 150 million computers will be recycled and 55 million landfilled in 2005 [34].

Electronic waste is the most obvious environmental problem as the infrastructure to manage it is still poorly developed. The recycling and reuse of post-consumer electronics is often either technically problematic, is not feasible economically or simply lacks appropriate physical infrastructure, which will require huge material investments to build. The lack of appropriate policy, that would put more responsibility on producer, is probably the largest limiting factor. Even though some good policy initiatives are being already taken on international level (such as EU WEEE Directive), much more policy action is required to address not only manufacturing, but also the growing world-wide problems of consumption.

The debate around the significance of ICT energy consumption

Many studies and sources of official statistics in USA indicate decoupling of energy consumption and GDP. For example, during 1996-98 the US GDP increased by 8% while energy use increased less than 1% [49]. During 1996-99 the energy intensity per GDP in USA declined by –3.4% compared to the decline during the oil crisis, which was –2.6% during 1973-86. More surprising, the decline of the late 90's occurred without any significant price signals or policy initiatives [30].

Several studies indicate that while the economic growth contributes to growing energy consumption, the much less energy intensive ICT sector will reduce or reverse this trend [11,31,43]. According to one report the ICT sector in US, where it has 7.5% in the economy, will further grow by 4.0% annually, while other sectors - only by 2.2%. At the same time the report predicts reduction of energy intensity by –0.92% [11].

Some research groups accredit the major part of this trend to the ICT sector and the *structural changes* caused by the sector.[7,8] One argument is that a large part of added value is created by ICT businesses, which manipulates ideas and information rather than energy and materials. Another argument rests on statements that ICT sector raised productivity in other sectors of economy by improving efficiency of process and product design as well as product operation.

Since estimating the direct impact of Internet on energy consumption is problematic the role of ICT sector in the energy decline is a subject for debate. Some researchers do not believe in reduction of net energy consumption or attribute the efficiency improvement to temporary climate variation – e.g. summers and winters in US were warmer at that time. Others refer to structural changes in US economy due to the explosive growth of digital economy, which is based on ICT sector and growth of Internet, especially e-commerce.[9]

One controversial article in “Forbes” magazine stated that it takes 1kg of coal to produce enough energy to send 5MBt of data over Internet and that in 1999 the Internet equipment consumed roughly 8% of total US electricity consumption, which can grow to 50% within a decade [35]. Better computer performance eventually contributes to more bits pored into the cyberspace and therefore larger energy demand. Energy efficiency improvements in electronics cannot outpace the growth in their numbers and increase in absolute energy demand [35,36]. The results were heavily criticised by a number of peers suggesting that the

[7] The structural change is “…the shift from energy-intensive industries as a source of economic growth, toward the less energy-intensive commercial services and light manufacturing segments of the {US} economy” (Laitner, 2000a).

[8] See also (Romm, 1999), (Kelly, 2000) and (Laitner, 2000a).

[9] For more information see articles by (Koomey, 2000), (Brynjolfsson, 2000b), and (Kovacs, 1999).

estimate should be reduced by at least 88%.[10] However, the numbers still look impressive even if an overestimation of a factor 10 has been done.

One issue that might be potentially overlooked in such estimations is that computers are multifunctional products able to integrate functions of many other devices such as telephones, faxes, video/audio and measurement equipment. Integration of their functions might reduce electricity consumption especially the losses of stand-by consumers. In addition, computers are being used to optimise energy use through automation and process control.

Another example shows opposite – one of the major telephone companies in California doubled or quadrupled data traffic over a five-year period while its energy use did not grow at all [28]. Other study shows the potential of electronic equipment. According to (Kawamoto et al., 2000) [25], power management in electronics currently saves around 30% of energy and another 23% could be saved with complete saturation and proper functioning of the power management tools installed. Shutting down redundant equipment not required to operate at night would reduce power consumption by additional 10%.

The debates eventually does not lead to clear answers even though accounting direct rebound effects on micro-level is much more easier than on macro-level, where rebound effects are probably much higher. Next section will look into what can be the effects from the ICT sector on a larger scale.

ICT on Macro-level: positive and negative effects

Nowadays the business value of computers is less limited by computational ability, but rather the ability to use them as a tool to reduce costs for co-ordination, communications, and information processing. The ICT facilitates reorganising management processes, creating new business models, improving resource planning, co-ordinating design, production operations, marketing and sales, and finally, changing our life styles. In a way it gradually becomes an economic lubricant reducing costs and contributing to growth of other economy sectors. Some of these developments may contribute to potential second order rebound effects in other sectors of economy.

---

[10] The issue is well reflected in the website of Lawrence Berkeley Laboratories http://enduse.lbl.gov/projects/infotech.html

One of the most obvious rebound-like effects in the ICT sector is paper consumption. Contrary to most expectations, the ICT did not create “paperless office”. Instead, the actual paper consumption with the advent of desktop publishing has increased several times (e.g. the increase in US between 1960-97 was five-fold).

As we failed creating paperless office, the ICT did not contribute to reduction in transport either. As Internet makes communication cheaper it increases long-distance links between people and businesses. Contrary to what was expected, the number of total kilometres travelled worldwide has increased as we find more needs for face-to-face meetings.

The ICT itself contribute making fossil fuels more abundant and cheap. The result of using computer technologies was that remote imaging and computer modelling increased probability of finding oil and other fossils fuels, which reduced the finding costs of a barrel of oil by more than 75% [36].

ICT and Trade

E-commerce is another area where ICT is dramatically changing the way we buy goods and services creating the so-called "frictionless market" where the cost of transaction is extremely low and information access is almost perfect. The Internet can successfully bring buyers and sellers together virtually in any place in the world and dramatically reduce the transaction costs in the process. The conditions for perfect market improve leading to increased competition, which affects retail prices and eventually consumption. Lower prices backlash in increased consumption and transport.

The “one-click-shopping” makes it extremely easy to find, compare and buy products and services. It also has great potential cutting transportation to the end consumer. Unfortunately, price and delivery time often become the two dominant criteria for purchasing decisions and only a few buyers take transport distances in to account. As a consequence, quick over-night door-to-door deliveries often negate the reduction of environmental impacts of individual transportation.

For example, vacation costs worldwide have plummeted thanks largely due to more efficient information on available travel tickets. One of the largest US online ticket sales companies trades 500.000 tickets daily for bidding customers. As a result more people can afford cheaper travelling and travel, so they do.

Even without efficiency improvements of any process, the e-commerce contributes to energy price reduction. An example can be from electricity market. The trends for market deregulation and large scale electricity auctioning in real time on the Internet drives down electricity prices.

With Internet penetration into developing countries, huge markets are exposed to new life styles. E-commerce provides a tool to obtain products and services that are not available or are too expensive on domestic markets. This further fuels global consumption.

In digital economy cheap information is economic lubricant accelerating the creation of wealth. Indeed, the global information space increasingly provides unlimited information at close-to-zero cost and allows us doing things more efficiently. While doing things more efficiently we can produce more using fewer resources. Decreased demand of natural resources potentially causes price reduction and growing consumption if no governmental intervention into market is done.

So even if e-commerce brings a lot of benefits environmental benefits by optimising retail processes, there is also no guarantee that the net effect will not be offset by increased consumption due to price reduction. In other words, the information revolution offers great possibilities for dematerialisation, but even if the material input per unit of GDP is reduced, the aggregate material use worldwide might be not.

Energy infrastructure

The growing complexity of Internet-PC infrastructure increasingly requires reliable power supply. Fast computers cannot tolerate power cut-offs contrary to refrigerators or light bulbs. For a processor running at 1GHz speed even a slightest power interruption of a billionth of a second is critical. Therefore, a huge infrastructure for reliable power supply (e.g. batteries, flywheels, magnetic superconductors, and uninterrupted power supply units) is being built around the semiconductors to provide power reliability for an e-factory or a dot-com enterprise. The reliability level of up to 99.99999999% is required in many industries, which is equivalent to power interruption time of less than 0.003 sec/year [36].

Not only the costs of such infrastructure are immense, but energy consumption as well. Energy utility suppliers like American Power Conversion and Active Power in USA are running heavy equipment to provide reliable power supply by spinning 1.5 ton flywheels at 7,700 rpm, or a 2MW super-conducting magnets of 750kg as power supply to backup generators. It seems that in the end the age of bits requires a lot of kilograms of heavy hardware [36].

Consumption changes

Consumption habits are pretty much tied with human psychology and behaviour. The view that we consume things only for their function is very simplistic. There are many other parameters affecting consumption desires and many are not related solely to product function, but rather human factors such as consumers taste (e.g. product form, colour, comfort of use, image and fashion, brand identity, sentiments, etc.). Economic and population growth worldwide will create even more possibilities for rebound effects. The technology reliance on ICT sector together with people's aspirations to adopt modern lifestyles are likely to contribute to consumption in the sector.

According to (Sachs, 1999) [44], human consumption desires are formed by two components - basic needs and quality related. The first one is driven by human aspirations to satisfy basic physical needs for food, clothing, shelter and mobility, while the second - by human desires to express a particular life style determined by the symbolic values of goods. There are good reasons to argue that electronic products experience a shift from being attributes of a certain life style to necessity goods as increasingly larger part of our lives relies on ICT infrastructure, products and services.

ICT allow us to save time by doing things faster and more efficient. Not surprising that saved time slots are filled with certain work or leisure related activities. Unfortunately, majority of our activities is tied with materials and energy consumption mainly constrained only by economic limits.

It is very hard to account what time of activity the empty time slots are filled with. The activities can be anything from low energy-intensive (e.g. cultural recreation, visiting museums, painting, etc.) to highly energy-intensive like travelling. Estimating such cross-sector rebound effects is particularly problematic due to a large degree of complexity of factors forming human behaviour.

Some interesting methodological approaches based on time-use analysis already exist providing valuable insights into time-budget related rebound effects [23]. The traditional explanation of rebound phenomena by income and price effects might be well supplemented by the time component especially in the ICT sector. With the current trend towards growing incomes and falling prices, the income constraints for rebound effects decrease and time budget constraint gains importance.

Productivity and innovation

The world's economy is dominated by market economies, where competition is the major driving force. Competition may take many forms, such as based on cost reduction, quality offer or innovation. Which form is most important is hard to say as it may vary among different sectors of economy, but innovation is probably the most powerful one for the ICT sector.

Innovation can be in form of a major technological breakthrough or small advancements. A lot of efforts are directed to the later, as major technological breakthroughs increasingly require large investments and research efforts. The small improvements are often not essential for product performance as some products are being perfected for decades and its main purpose is to differentiate from competitors. For example, how much one needs to perfect a pen to improve it functionality? There are already pens writing on any surface and in any conditions. These small improvements do not essentially improve the quality of life, but still require natural resources and promote irrational consumption through marketing pressure.

The ICT remains highly innovative sector, which in turn facilitates rapid depreciation of electronic products. There is a reason to believe that high expectations of business returns from investments into the sector are largely responsible for its quick development. The computer role in productivity growth is a subject for an on-going debate, which is highly important businesses and policy makers, whose perceptions might strongly affect the consumption in the ICT sector.

Computers and Productivity Growth

Some signs of decoupling between energy use and GDP generation have recently emerged showing that economic growth shifted away from energy intensive sectors.[11] A large part of it is accredited to the ICT sector - its contribution to structural changes and the emergence of so-called *New Economy.* There might be several reasons for that - an increasingly large part

---

[11] The US annual GDP change in pre-Internet era during 1992-96 was +3.2% with corresponding growth of energy demand +2.4%. The same figures for 1996-2000 when ICT industry accounted for nearly 1/3 of real GDP growth in US were +8% and +1% respectively [44].

of added value is being created by businesses that manipulate ideas and information instead of energy and materials [43]. Also the use of computers might contribute to raising productivity in other sectors of economy.

However, the role of computers in the efficiency improvements (the so-called *computer productivity paradox*) is currently under debate. The question is how does industry computerisation actually affect economic productivity. There are opinions that expectations from investments into information technology are overvalued and there is too much reliance on hardware and too little on organisational changes and peoples' knowledge.

Unfortunately, despite the efforts of many scholars, not much of reliable information on computer role in productivity can be extracted from official statistics. According to Solow, the overall economic productivity despite huge investments in ICT sector has grown more slowly since 1973, that during 1950-73: "…*we see the computer age everywhere expect statistics*" [46].

Since the beginning of 1980's several empirical studies of economic productivity have been performed in US showing mixed results. The majority indicate very small or insignificant effects of ICT on productivity growth.[12] Results from a number of studies show computer-induced productivity growth rate around 0.3 - 4%.[13] The variety of results has lead to on-going debate about the significance of computer role in economy and the ways to measure productivity growth.

Experts attribute productivity improvement to an increasingly effective use of two important growth factors: *new computer technologies* and *outsourcing*. By outsourcing their non-core business activities organizations can specialise accumulating required knowledge, better allocating resources and increase productivity. The effective use of computer technologies has become critical to businesses' growth helping to streamline increasingly complex business processes and ensuring faster growth.

During the last five years the US GDP has grown an average 4% per year, while the consumer price index has risen only 2% during 1996-99. (Unterberg, 2000) [48], argues that this was possible, because organizations have become more productive and average

---

[12] For more information see (Harris, 1992) and (Parsons, 1992), ref. (Gunnarsson, 2000).

[13] See (Oliner, 1994), (Jorgenson, 1995), (Brynjolfsson, 1996) and (Brynjolfsson, 1997b).

productivity per manufacturing hour worked has grown at 5% during last five years mainly thanks to computerisation.

However, other opinions say that the ICT sector does not drastically improve economic productivity outside its own sector. (Landauer, 1996) [32], states that in spite of huge investments in ICT sector over the last twenty years, productivity in many service industries virtually stagnated everywhere in the world. Especially the development of internal skills within many organisations might become a chronic problem at rapid pace of software and hardware updating. (Attewell, 1994) [2], acknowledges productivity losses while adjustments in working practises are under way in order to adjust to frequent the software and hardware updates.

Some experts say that the investments in the ICT sector might need more time to payoff by productivity increases, as time is needed for human capital to absorb new technologies [19]. According to (Brynjolfsson, 2000) [7], computers on a short term contribute to output roughly equal to their factor share, meaning that the contribution is to the output growth rather than productivity, while over longer time horizons, computers contribute 2-8 times than their factor share. Therefore, analysing economic returns on longer term might better represent the effects of ICT investments.

The analysis of computer productivity growth is complicated, because of a number of uncertainties and the variety of accounting methods used. Traditionally the productivity is measured as a ratio between inputs and outputs. These are problematic to determine in the ICT sector. Most traditional accounting methods do not take into consideration intangible costs and benefits, such as higher employee competence, costs of developing new software and databases, implementing new business concepts and reorganising management of the enterprises. Most these assets go largely unaccounted in a firm's balance sheet. According to (Brynjolfsson, 2000) [7] if this would be accounted, a 1 dollar of ICT capital in a typical firm should accumulate $4-$19 in additional intangible assets.

The accounting methods based on financial market data (e.g. Tobin's-q indicator, which measures the rate of return based on comparing the stock market value of a firm to the various capital assets the firm owns) might not be reliable too, because of the overvaluation of ICT related stocks. Using the data of for Fortune 1000 firms in 1987-94 (Brynjolfsson, 1997b) [5] found that "…*while one dollar of ordinary capital is valued at approximately one dollar by the financial markets, one dollar of IT capital appears to be correlated with between $5 and $20 of additional stock market value*". The recent IT stock crashes proved how volatile these stocks are. This poses a question if current valuation of ICT sector on stock market gives a realistic reflection of its actual productivity.

Swedish industry has started heavy ICT investments even earlier than USA. (Gunnarsson, 2000) [19] has analysed a sample of 14 industries in Sweden and concluded that human capital is the key to curb the productivity paradox, emphasising the importance of high-skill labour to fully utilise ICT potential by combining it into business practices.

It seems that human factor is an important aspect for utilising ICT sector potential to increase productivity. Many firms that absorbed ICT pay too much attention on hardware investments and too little to human capital. The most productive firms are more likely to have high degree of computerisation and high level of human capital in form of knowledge and experience.

In order to be successful an enterprise along with computerisation must adjust its work practices adopting the ICT as part of a system that reinforces its organisational changes. Changing incrementally, making computer investment with little or no organisational change an enterprise risks suffering productivity losses. A combination of computerisation and organisational co-investments in human capital makes a substantial contribution to economic growth. On governmental policy level this means that more can be achieved by putting less emphasis on policies promoting heavy computerisation by investments in hardware and focusing more on policies that support knowledge building and finding more productive ways of using ICT hardware.

Summing up there are several points worth stressing:

1. In order to better account for productivity changes caused by computerisation, the intangible company benefits must be accounted,
2. the quality of existing services still rely on human skills and large investments into ICT infrastructure pay back only marginally,
3. the use of computers is often limited to small number of relatively simple tasks and there is a risk of investment into over-quality of hardware,
4. the majority of investments into ICT infrastructure depreciate very fast; at the same time employees must be retrained continuously to be able to work most efficiently,
5. parallel investments into organisational changes must be done along with the investments into ICT infrastructure.

Discussion on government role

The traditional governmental and business efforts directed to promote resource efficiency and productivity growth are certainly playing an important role in reducing environmental impacts, even though the efforts can backfire in increased consumption due to rebound effect. There are a lot of good environmental initiatives in industry with the focus on product eco-design. However, the majority of these efforts do not explicitly address the issue of growing consumption and potential rebound effects. While businesses are not directly interested in dealing with growing consumption, it is the role government to play a more active role in steering consumption-related issues.

By using different policy mixes governments can create incentives for industry to develop new business approaches based on dematerialised products and services. The ICT sector has an exceptionally large potential to replace many physical products with software-based substitutes and still promote economic growth without increasing material and energy consumption. Different instruments including regulatory, economic, information and regional planning are known and are relatively well explored.

Setting standards

The government could for example set energy or material intensity standards for raw material extraction and manufacturing in the ICT sector. However, standard setting should be done with caution, as it does not encourage the producers going beyond the required standards. The procedure of standard setting can also be potentially very complex and require extensive administrative and enforcement apparatus. Due to huge variety and global production of electronics it can easily turn to be impractical. Such efforts also require international cooperation, which is another complication.

Bans

Governments on national and international levels can ban the use of certain hazardous substances in electric and electronic equipment. For example EU has proposed a directive on the "Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment" (ROS) that requires substitution of cadmium, chromium (VI), lead, mercury and certain flame-retardants with exceptions for some electronic products groups.[14] Such initiatives can become effective means to swiftly reduce the use of "problem" substances and they are easy to administrate.

---

[14] Provisional, 2000/0159COD, COM 2000 Nr. 347, June 2000, Brussels.

The use of prescriptive tools, such as the EU ROS directive, has several limitations. First, since it is targeting production stage and does not affect the consumption stage. At the same time it is crucial to ensure that the substitutes will not lead to more detrimental environmental impacts such as higher toxicity or larger material intensity. The alternative substances might also increase the costs of equipment and the recycling costs due to larger variety of the substitutes (and decreasing concentrations in the waste streams). Similar policy initiatives can become a serious trade barrier unless they target products that are not traded internationally. Already now some governments and industry associations are opposing the initiative using similar arguments [50].[15]

Using economic instruments

Economic instruments, such as taxes and subsidies, can more effectively create incentives for designing product and service systems by internalising their environmental costs. Taxes on virgin natural resources could differentiate charges for renewable and non-renewable raw materials giving price signals to producers on what resources to use. Such changes in resource pricing may create better market opportunities for new businesses that rely on dematerialised product and service systems. The collected revenues can be used to compensate high reuse and recycling costs and support industries and local municipalities in building appropriate infrastructures for end-of-life management of electrical and electronic waste.

The economic instruments are also more favourable, because they can address product related environmental impacts in several life cycle stages at the same time.

Eco-labelling

Eco-labelling is another effective policy instrument to promote reduction of product-related environmental impacts. Different national and international labelling schemes for ICT products already exist (e.g. Energy Star®, TCO, Blue Angel, EU eco-labelling schemes for personal and portable computers).[16,17,18, 19]

---

15 For example US Chamber of Commerce, American Electronics Association, European Association of Consumer Electronics Manufacturers and Electronics Industries Alliance.

16 http://www.energystar.gov (2001.04.01)

17 http://europa.eu.int/comm/environment/ecolabel/index.htm (2001.04.01)

18 http://www.tco-info.com/i/index.html (2001.04.01)

19 http://www.blauer-engel.de/Englisch/index.htm (2002.04.01)

Eco-labelling can be designed to be both voluntary and obligatory. In voluntary labelling schemes manufacturers are not directly penalised for being unable to reach a required resource intensity standard leaving it to consumers to chose which product to buy. Using obligatory labelling a producer might be not allowed to sell a product without informing consumers about the discounted lifetime costs from using a product or a service.

Using eco-labelling might be problematic though, due to international trade agreements or even due to purely practical reasons - it is difficult to calculate the lifetime costs for products with a difference between economic and physical lifetimes. Without active participation of consumers the eco-labelling of ICT products will be significantly less effective, e.g. there is a little benefit using an EnergyStar® labelled product if a user does not activate its energy saving features.

The short life span of ICT products is linked to growing amounts of toxic electronic waste. The upcoming EU Directive on Waste Electric and Electronic Equipment is one of the policy instruments on international level that is designed to create incentives to address the problem of waste in the end-of-life stage. It is anticipated that the Directive will lead to extension of product life through design for upgradability, re-manufacturing and recycling. The new design approaches can slow product obsolescence, increase customers' loyalty, lower their product ownership costs, and improve product serviceability. The Directive might also lead to alternative business models where the use of physical products is substituted by function sales. The ICT products are unique in this sense as the majority of their functions can be delivered without actual ownership of the hardware.

From the discussion following approaches can address the problem of rebound effects from the ICT sector: eco-taxes, dematerialisation, normative approaches, eco-design and efficiency improvements.

Social costs of environmental impacts can be partly internalised by alternative prising mechanisms using environmental taxes, charges, fees etc. Emphasis should be also given to systems design such as promotion of new business models and technical design approaches that rely on dematerialised product systems. Normative approaches that address sustainable lifestyles through information and education should not be underestimated too despite the existing scepticism. New generations should adopt lifestyles that are different from today, based on social values and environmental responsibility.

Understanding whether, how and to which extent does the ICT sector influence economic productivity is an important issue for policy makers and business leaders setting priorities and making trade-offs between economy and environment. Having more information on the ICT sector's role in structural changes governments will be better informed when developing new policy frameworks to address global environmental problems. More information helps to identify, track and evaluate alternatives when allocating financial resources for environmental programmes in different economic sectors. The investments and efficiency improvement efforts may lead to better results if turned from focus on ICT hardware to "soft" issues, such as better use of knowledge and information, improved managerial practices and creation of new business models based on less material intensive and more productive ICT products and services.

General conclusions

The ICT sector is a very dynamic and rapidly developing sector and the material and energy efficiency of electronic products has improved dramatically. At the same time the consumption of electronic products has increased causing serious doubts about the effectiveness of the improvements for resource conservation. Signs of rebound effects are already emerging in the ICT sector, but still there is no clear picture about resource consumption trends and ICT sector inter-linkages with other sectors of economy.

There are many reasons to believe that the role of ICT in productivity growth is overestimated. However, the sector will certainly play the major role in economic development and it is crucial that its development will be in line with sustainable development visions. Right priorities have to be set for environmental protection actions to enable optimal allocation of financial and other resources.

The traditional view on ICT as clean technologies is gradually changing. We start to realise that the environmental impacts from the ICT sector occur not only in the end-of-life stage. The manufacturing and user phases are associated large environmental impacts due to high material and energy inputs. Raw material extraction has high mining waste volumes and semiconductor manufacturing increasingly requires a lot of energy, toxic materials and high levels of purity, especially with continuing trend to miniaturisation. The growing consumption of electronic products will only amplify these environmental impacts.

It is still not clear whether the rate of efficiency improvements in the ICT sector have overcome the general growth rate of natural resource consumption by the sector. A rebound-like effect can potentially occur not only in the ICT sector itself (on micro-level), but also in other sectors (macro-level) due to the structural changes caused by ICT sector, which affects all sectors of economy changing resource consumption patterns, organisational structures and people's lifestyles. The effects here might be even much larger. Unfortunately, there are no comprehensive studies about this effect as this area is relatively new and data for quantitative estimations is still poor.

Even though, it is not certain how large the rebound effects are from the sector itself and if they are linked to the other sectors of economy, i.e. the second order effects. The later are likely to be significant compared to the direct rebounds, but they are hard to estimate and anticipate due to the complexity of inter-linkages between different economy sectors. While it is possible determine the effects conceptually, it is too early to determine them empirically and the results would probably be impractical to use due to high degree of uncertainty.

Nevertheless, the policy makers should not underestimate the role of ICT in other sectors and long-term research in this area should be encouraged. The two key areas where optimal policy decisions require more knowledge are related the role of ICT sector in global economy and the balance between innovation and the speed of development.

New governmental policies should not hinder innovation and endorse technologies that most effectively promote sustainable economic growth. The value of human capital in form of knowledge and skills to use the technologies should not be overestimated and more support to education can be very rewarding both environmentally and economically.

The policy approaches for ICT sector must be broad enough to support collection systems, creation of markets for recycled and reused products, promote business dematerialisation and knowledge upgrade. The reduction of the environmental impacts of a product can be achieved through *dematerialisation* and *extension of useful product life*. Dematerialisation is one of the most effective means of product environmental improvement, and its potential can be particularly well utilised in the ICT sector where new business approaches relying on less material product and service systems are relatively to create.

With no doubt the issue of potential rebound effect from the ICT sector is worth attention from policy makers. Huge investments are being made within the sector with large expectations for economic growth the environmental improvements. Neglecting the issue of rebound effect causes a risk of misallocation of funds, but having more information on effects and causes will allow policy makers to optimise future development with a balance between economic growth and environment.

References

[1] Anzovin, S. *The Green PC Revisited*. ComputerUser.com Ltd., 1997.

[2] Attewell, P. *Information technology and the productivity paradox*. In: D.H. Harris (ed.) Organizational linkages: Understanding the productivity paradox. Washington, DC, National Academy Press, 1994.

[3] Brookes, L.G. *Communications. The greenhouse effect: Fallacies in the energy efficiency solutions*, Energy Policy, 3, pp. 199-201, 1990; *Energy Efficiency and Economic Fallacies - A Reply*. Energy Policy, 20(5), pp. 390-392, 1992; *Energy Efficiency Fallacies - The Debate Concluded*. Energy Policy, 21(4), pp. 346-347, 1993.

[4] Brynjolfsson, E., Hitt, L. *Computers and Productivity Growth: Firm-Level Evidence*. Cambridge, MA, Sloan School of Management, Massachusetts Institute of Technology), 1997.

[5] Brynjolfsson, E., Yang, S. *The Intangible Costs and Benefits of Computer Investments: evidence from the final markets*. International Conference on Information Systems, Atlanta, Georgia, USA, 1997.

[6] Brynjolfsson, E., Renshaw A., Alstyne, M.V. *The Matrix of Change*. MIT, Sloan School of Management, Cambridge, Massachusetts, 1997.

[7] Brynjolfsson, E., Hitt, L.M. *Beyond Computation: Information Technology, Organisational Transformation and Business Performance.* MIT, Sloan School of Management, Cambridge, Massachusetts, 2000.

[8] Brynjolfsson, E. *Information Technology and Productivity: a review of the literature. Advances in Computers*. MIT, Sloan School of Management, Cambridge, MA; University of Pennsylvania, Wharton School, Philadelphia, PA, 1996.

[9] Clegg, A.J.W., D. J. (ed.) *The Strategic and Competitive Implications of Recycling and Design for Disassembly in the Electronics Industry.* IEEE, 1994.

[10] Cook, C.D.T., Clay, A. *Silicon hell*. SFBG News, 2000.09.15.

[11] EIA, *Annual Energy Outlook 2000.* Washington, DC, U.S. Department of Energy, 1999.

[12] Frey, S. *Environmental Assessment of Electronic Products Using LCA and Ecological Footprint*. Joint International Congress and Exhibition. Electronics goes green 2000. Berlin, Germany, 2000.

[13] Goldberg, C. *Where Do Computers Go When They Die?* Technology Circuits. New York Times of the Web, 1998.

[14] Greene, L.D. *Vehicle Use and Fuel Economy: How Big is the «Rebound» Effect?* The Energy Journal, 1992, 13(1), pp. 117-143.

[15] Greene, L.D.K., J.R.; Gibson, R.C. *Fuel Economy Rebound Effect for U.S. Household Vehicles*. The Energy Journal, 1999, 20(3), pp. 31.

[16] Greening, L.A.G., David L.; Difiglio, C. *Energy Efficiency and Consumption - the Rebound Effect - a Survey*, Energy Policy,2000, 28(6/7), pp. 389-401.

[18] Grepperud, S. *A General Equilibrium Assessment of Rebound Effects.* Programme for Research and Documentation for a Sustainable Society, University of Oslo, 1999.

[19] Gunnarsson, G.M.E.; Savvidou, E. *Is Human Capital the Key to the IT Productivity Paradox?* JEL, Mälardelens Högskola, Sweden, 2000.

[20] Harris, S.E., Katz, J. L. *Organizational Performance and Information Technology Investment Intensity in the Insurance Industry,* Organizational Science, 1992, 2, pp. 263–296.

[21] Hunter, L.W., Bernhardt, Annette, Hughes, Katherine L., and Eva Skuratowicz. *It Is Not Just the ATMs: Firm Strategies, Work Restructuring and Workers' Earnings in Retail Banking*. Wharton School, Philadelphia, Pennsylvania, 2000.

[22] IPU, Atlantic Consulting. *LCA Report: EU Eco-label for Personal Computers*. Lyngby, Institute of Product Development, Technical University of Denmark; Atlantic Consulting, USA, 1998.

[23] Jalas, M. *A Time-Use Approach on the Materials Intensity of Consumption*. Helsinki, Helsinki School of Economics and Business Administration, Department of Management, 2000.

[24] Jorgenson, D.W., Stiroh, K.J. *Computers and Growth, Economics of Innovation and New Technology,* 1995, 3, pp. 295-316.

[25] Kawamoto, K., Johathan, G., Nordman, B., Brown, R., Piette, M.A., Meier, A.K. Electricity Used by Office Equipment and Network Equipment in U.S. Berkeley, University of California, LBNL, Environmental Energy Technologies Division, Energy Analysis Department, 2000.

[26] Kelly, H. Information Technology and the Environment: Choices and Opportunities Released. Digital Divident, iMP Magazine, 2000.

[27] Khazzoom, J.D. Economic Implications of Mandated Efficiency Standards for Household Appliances. The Energy Journal, 1980, 1(4), pp. 21-40.

[28] Koomey, J.G. Rebuttal to Testimony on 'Kyoto and the Internet: The Energy Implications of the Digital Economy'(Berkeley, Energy Analysis Department, Environmental Energy Technologies Division, LBNL, University of California, USA, 2000.

[29] Kovacs, C.M. Environmental Benefits from the Dematerialization of Services Case study: Digital publishing. Screening LCA on two alternative services for scientific information provision. Amsterdam, University of Amsterdam, IVAM Environmental Research, 1999.

[30] Laitner, J.A.S. The ICT Revolution: Can It Be Good for Both the Economy and the Climate? Washington, DC, US EPA Office of Atmospheric Programs, 2000.

[31] Laitner, J.A.S. Jonathan G.; Worrell, E.; Gumerman, E. Re-estimating the Annual Energy Outlook 2000 Forecast Using Updated Assumptions about the Internet Economy. The Eastern Economics Association Conference. Crystal City, Virginia, US, LBNL, 2000.

[32] Landauer, T. The Trouble with Computers: Usefulness, Usability, and Productivity. MIT Press, Massachusetts, 1996.

[33] Levy, F.B., Anne; Murnane, Richard J; and David Autor. Computerization and Skills: Examples from a Car Dealership mimeo. MIT and Harvard, 2000.

[34] Matthews, H.S.M., Francis C.; Hendrickson, Chris T.; Hart, Diana J. Disposition and End-of-Life *Options for Personal Computers*. Pittsburgh, Carnegie Mellon University, 1997.

[35] Mills, M., P.; Huber, Peter, W. Dig more coal -- the PCs are Coming. Forbes Magazine, 1999.

[36] Mills, M.P. Forget Oil. It's The Century of the Electron. The Wall street Journal, 2000.

[37] Murnane, R.J.L., Frank; and David Autor. Technological Change, Computers and Skill Demands: Evidence from the Back Office Operations of a Large Bank. NBER Economic Research Labour Workshop, 1999.

[38] NEC Corporation. Environmental Management Activities at NEC. "Product Evaluation Through LCA. NEC Corporation, Resources and Environment Protection Research Laboratories, 1999.

[39] Oliner, S.D., Sichel, D.E. Computers and Output Growth Revisited: how big is the puzzle? Bookings Papers on Economic Activity, 1994.

[40] Orlikowski, W.J. Learning from Notes: Organizational Issues in Groupware Implementation. In: J.T.R. Kraut. (ed). Conference on Computer Supported Cooperative Work (Toronto, Association for Computing Machinery, 1992.

[41] Parsons, D.G., Calvin, C.; Michael Denny. Productivity and Computers in Canadian Banking. Journal of Productivity Analysis, 1992, 4, pp. 95–113.

[42] Radermacher, F.J. Building the Information Society, in: R.W. Sturm, G.; Will O. (ed.) Information Society and the Regions in Europe. University of Tübingen, 1997.

[43] Romm, J.R., A.; Herrmann S. The Internet Economy and Global Warming. Washington, DC, The Centre for Energy and Climate Solutions, The Global Environment & Technology Foundation, 1999.

[44] Sachs, W. Rich in Things, Poor in Time. Journal 'Resurgence', September-October, 1999, Issue 196, pp. 4.

[45] Saunders, H., D. A View from the Macro Side: Rebound, Backfire, and Khazzoom-Brookes. Energy Policy, 2000, 28(6-7), pp. 439-449.

[46] Solow, R. We'd Better Watch Out. New Year Times Book Review. New York, USA, 1987,

[47] SVTC. Water Use and other Materials and Wastes Associated with Semiconductor Production. Silicon Valley Toxics Coalition (SVTC), USA, 2000.

[48] Unterberg, C.E. ASPs Will Help Drive Our Global Economy. ASP News.com, 2000.

[49] USDC, *Digital Economy 2000*. US Department of Commerce. Economics and Statistics Administration, 2000.

[50] Dworak, T., Kuhndt, M. *Discussion Paper on Return of Used IT-products, Reuse and Recycling*. Wuppertal Institute, Eco-Efficiency & Sustainable Enterprises Team, Wuppertal, Germany, October 2000.

Illustrations

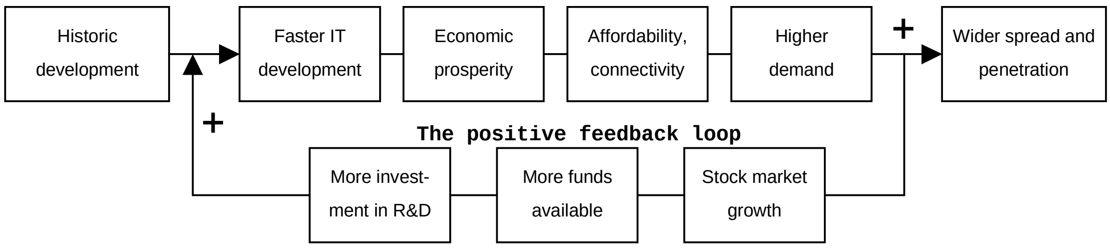

Figure 1. The positive feedback loop fuelling the growth of the ICT sector

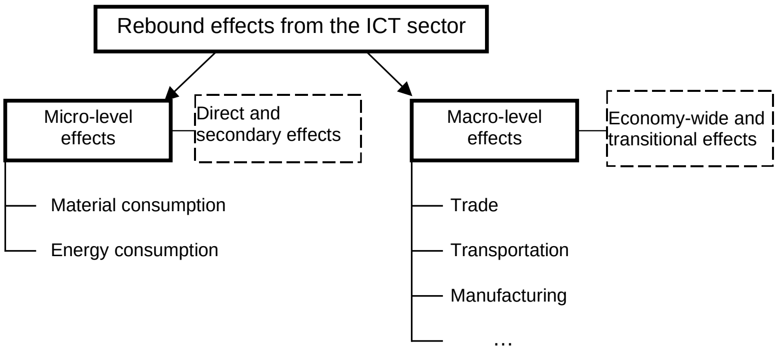

Figure 2. Areas of rebound-like effects in ICT sector

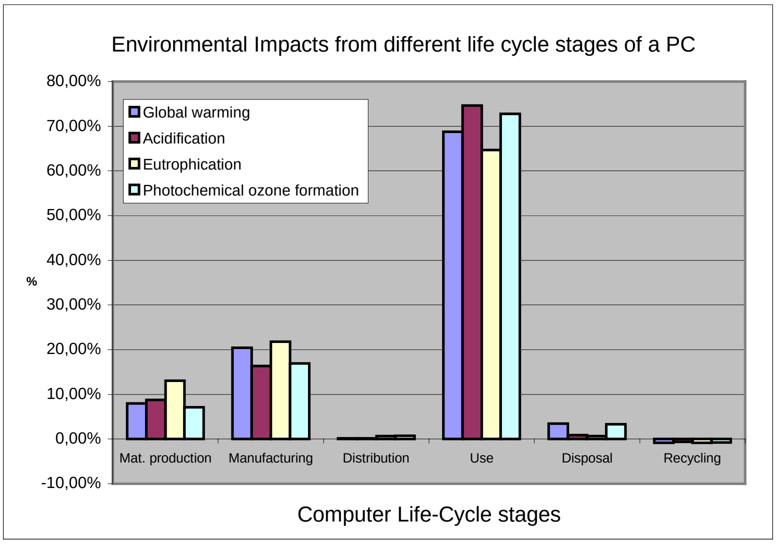

Figure 3. Environmental impacts of different computer life-cycle stage (data from (IPU, 1998)).

Tables

Table 1: Characterised environmental impact potential, PC and packaging

Environmental impact categories	Unit	Material product.	Manuf.	Distrib.	Use	Disposal	Credit for recycling	Total
Global warming	kg CO_2-eqv	51 800	133 000	0.959	447 000	22.300	-5.370	650 000
Acidification	kg SO_2-eqv	0.485	0.908	0.010	4.140	0.050	-0.035	5.550
Nutrient enrichment	kg NO_3-eqv	0.332	0.560	0.016	1.650	0.017	-0.022	2.550
Photochemical ozone (high NO_x)	kg C_2H_4-eqv	0.012	0.029	0.001	0.123	0.006	-0.0013	0.169

Table 2: The division of Global Warming Effect between life cycle stages of PCs.

LC stage:	Use	Manufacturing	Transport	Disposal
Desktop PCs	80%	19%	1%	<<1%
Laptop PCs	55%	45%	<<1%	<<1%

Source: NEC Corporation, Resources and Environment Protection Research Laboratories (NEC Corporation, 1999).