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Please cite this paper as:

Enck, J. and T. Reynolds (2009-12-09), "Network Developments in Support of Innovation and User Needs", *OECD Digital Economy Papers*, No. 164, OECD Publishing, Paris.
http://dx.doi.org/10.1787/5kml8rfvtbf6-en

OECD Digital Economy Papers No. 164

Network Developments in Support of Innovation and User Needs

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OECD

Unclassified **DSTI/ICCP/CISP(2009)2/FINAL**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **09-Dec-2009**

English - Or. English

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INDUSTRY
COMMITTEE FOR INFORMATION, COMPUTER AND COMMUNICATIONS POLICY

DSTI/ICCP/CISP(2009)2/FINAL
Unclassified

Working Party on Communication Infrastructures and Services Policy

NETWORK DEVELOPMENTS IN SUPPORT OF INNOVATION AND USER NEEDS

English - Or. English

JT03275973

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FOREWORD

This paper has been drafted in co-operation with the Working Party on the Information Economy with input from the International Energy Agency, the International Transport Forum, the OECD Directorate for Education and the OECD Health Division. This report was presented to the Working Party on Communications Infrastructure and Services Policy (CISP) in June 2009 and declassified by the Committee for Information, Computer and Communications Policy (ICCP) in October 2009.

The report was prepared by James Enck of mCAPITAL in conjunction with Taylor Reynolds of the OECD Secretariat as a contribution to the OECD's Innovation Strategy.

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MAIN FINDINGS

"WE DECLARE that, to contribute to the development of the Internet Economy, we will (...) stimulate investment and competition in the development of high capacity information and communication infrastructures and the delivery of Internet-enabled services within and across borders."

- OECD Ministerial Declaration (Seoul, June 2008)[1]

This report makes a case for investment in a competitive, open-access national fibre-to-the-home network rollout based on potential spillovers in four key sectors of the economy: electricity, health, transportation and education.

This research offers a new approach to evaluating the costs of building the most forward-looking network possible by evaluating what short-term cost savings (benefits) would have to be achieved in other key economic sectors to justify the investment. On average, a cost savings of between 0.5% and 1.5% in each of the four sectors over ten years resulting directly from the new broadband network platform could justify the cost of building a national point-to-point, fibre-to-the-home network.

If the cost savings in these and other industries are potentially large enough to justify the investments then governments have an incentive to find ways to encourage rollouts to capture the social gains. While the calculations in the paper are rough estimations they clearly highlight the fact that investments in fibre networks can be justified relatively easily through minimal cost savings in other sectors even when the savings are often discounted in investment calculations by private firms.

Policy and regulatory measures to promote competition in a next generation environment should be based on a sound economic assessment of specific market conditions and local factors. Proposals for government investment in FTTH networks should include a thorough cost-benefit-analysis which considers any potential deployments of next-generation networks by the private sector and any public funding of networks must be evaluated and targeted to avoid market distortions and crowding-out of private investment.

There could be cases where the social returns of broadband connectivity are potentially much larger than the costs of building the network but the operators do not invest because their private returns would not justify the investment. The inability of markets to take into account network externalities can lead to non-optimal provisioning of services and potentially limit innovation.

Some OECD governments have committed substantial economic stimulus funds to the rollout of broadband networks. This paper proposes that these investments could have an important impact in other sectors in the economy, helping justify the initial investments. Previous OECD work on the role of communication infrastructure investment in economic recovery lays a broad framework for government investments in communication networks while this paper looks at justifications for these investments based on potential returns in other sectors.

High-speed communication networks are a platform supporting innovation throughout the economy today in much the same way electricity and transportation networks spurred innovation in the past. Future innovations in many sectors will be linked to the availability of high-speed, competitive data networks and new applications they support. The emergence of many of these innovative services tied to broadband are visible today in four key sectors: electricity, health, transportation and education.

Data networks can serve as the foundation of new, *smart* electrical grids (advanced metering infrastructure) by addressing an historical information gap between end-users and distributors. Enabling communication via broadband can provide consumers a vision of their electricity consumption in real time as well as the overall supply and demand situation, allowing them to adjust consumption based on price signals. For the electricity provider, the smart grid allows operators to stabilise demand by monitoring and influencing consumption in real time either through technical intervention or variable demand-based pricing. Smart grids also promise to help manage electricity storage throughout the network which could be used to steady demand patterns during times of peak demand.

Health systems are facing tremendous pressure to improve health quality, accessibility and outcomes, and to do so in a cost-effective manner, particularly as the overall population ages. Broadband increases the potential for more doctor-to-patient interaction between hospitals/doctors and end-users at home. Two specific areas where broadband will likely have a significant impact in e-health are increasing the efficiency of health monitoring and reducing the costs on the system via remote consultation and intervention, particularly as the percentage of the population over age 65 rises significantly.

Transportation planners struggle to understand traffic flows because there are not sufficiently robust means to collect traffic data, analyse and model it in real time and then pass the results along to all concerned drivers and commuters, helping them alter their routes. Broadband networks and access to the resources they provide form the foundation for collecting and distributing timely transportation information. This information, provided to traffic control systems and delivered to commuters to aid in route planning can help reduce traffic congestion, lower fuel consumption and help users avoid accidents.

Broadband is having a significant impact on education and e-learning by improving access to digital learning resources; encouraging communication among schools, teachers and pupils; promoting professional education for teachers; and linking local, regional and national databases for administrative purposes or supervision.

New high-speed broadband networks are also impacting other sectors of the economy not considered as part of this analysis. Broadband has become the leading delivery system for a wide range of content as witnessed by the transformation of the newspaper, music and video industries. Broadband is also the foundation of innovations in cloud and grid computing which efficiently centralise computing power and resources across the Internet and enable the rapid scalability of services in sectors such as transportation and education. Spillovers in these sectors, which are not included in the calculations, could also help justify large investments in a national high-speed network.

Policy implications

Policy makers need to consider the potential spillovers of new broadband platforms when considering any public investment in new networks and when assessing potential regulatory requirements on next-generation networks.

Policy makers should also continue promoting private-sector investment and competition whenever possible to reduce the need for public funds to be directed to broadband projects.

Innovation thrives on open platforms with expansive bandwidth for new applications. Government should promote network technologies and topologies which are the most flexible, create the most opportunities for competition, offer the highest potential for innovation and those which can provide the most bandwidth in the future.

Policy makers and networks planners should focus on developing a broadband platform which easily supports capacity upgrades to match the bandwidth demand of new applications as they appear. Bandwidth constraints should not inhibit innovation.

Certain sectors will require higher-quality connections than many current broadband networks provide to households. Health applications, in particular, will require very low latency and high quality of service guarantees in order for tele-health applications to work safely and efficiently. New next-generation network rollouts will need to consider these requirements in the design phase in order to capture the benefits of certain services. Certain applications could potentially require a dedicated second fibre to the household in order to function optimally. Symmetric bandwidth will also be increasingly important.

Upload speeds over the network will become an increasingly important determinant of innovative capacity. The bandwidth dedicated to downloading is often 10 to 16 times higher than the bandwidth set aside for uploads. This creates an unfortunate dilemma for users, in that their ability to acquire content is vastly enhanced, while their ability to submit content back to the network does not grow proportionally.

High-speed broadband is increasingly considered a general purpose technology. There have been suggestions that a utility-style model for installing and maintaining passive infrastructure such as ducts and poles or dark-fibre connections could promote competition and provide connectivity particularly in areas where private firms have not found it profitable to build out next-generation networks. A utility-style model may also require lower returns than a similar private investment, thus reducing costs and making rollouts more economically feasible.

Access to high-speed broadband is an important foundation for innovation but there are a number of other roadblocks and bottlenecks which slow down innovation and may hinder implementation in sectors and minimize broadband’s impact even when it is available. Any broadband investment with the goal of cost savings in other sectors should be coupled with initiatives to ensure a smooth transition from existing service models and address any bottlenecks which could hinder adoption and innovation.

INTRODUCTION

In the June 2008 Seoul Ministerial Declaration, OECD Ministers jointly state their common desire to promote the Internet Economy and stimulate sustainable economic growth and prosperity by means of policy and regulatory environments that support innovation, investment and competition in the ICT sector (OECD, 2008a).

Ministers declare that to contribute to the development of the Internet Economy, they will (…) stimulate investment and competition in the development of high capacity information and communication infrastructures and the delivery of Internet-enabled services within and across borders. In addition, Ministers agree to foster creativity in the development, use and application of the Internet, through policies that maintain an open environment that supports the free flow of information, research, innovation, entrepreneurship and business transformation.

The Seoul Declaration provides the OECD with instructions for future work to support these elements of the declaration. The OECD is instructed to further the objectives set out in the declaration by analysing (…) the important role and contribution of the Internet and related ICTs as a driver of innovation, productivity and economic growth. The OECD is then directed to develop and promote policy and regulatory principles, guidelines, other instruments and best practices for the future development of the Internet Economy.

This paper is intended to support two key elements of the Ministers' declaration – stimulating investment and competition in broadband networks and developing policies which maintain an open environment which supports innovation. This paper will also serve as an input to the OECD's Innovation Strategy by examining the relationship between investment in physical networks and potential impacts in other large sectors of the economy.

Finally, the economic crisis has focused attention on government investments as a way to stimulate demand in recession-hit countries while also expanding the long-run productivity capacity of the economy. This paper is a follow-up paper to two recent OECD publications concerning government responses to the economic crisis. Both documents (OECD 2009a, OECD 2009b) highlight the important role of communication investment in economic stimulus packages as a way to address declining demand while simultaneously building a foundation for future innovation and productivity growth. This paper extends the research by looking specifically at the costs of building a national, fibre-based broadband network and comparing them to the cost savings in four key economic sectors which would be necessary to justify the investment from a public perspective in cases of market failure.

Networks are a key foundation for innovation

Network infrastructures such as roads, water, rail, electricity and communications all support the movement of physical goods or information throughout the economy. Each of these networks has played an important role in supporting innovation and growth partially by transporting necessary elements of production from one location to another. This "transporter" role is one key underpinning of a network's impact on innovation and economic growth.

Network expansions benefit innovation because they reduce the costs of transporting the factors of production and effectively increase the potential size of the market. Economic growth scholars emphasise that the size of a market is a function of these transportation costs (Mathias, 1969 & 2001). Larger markets mean lower production costs due to economies of scale and higher potential returns for entrepreneurs.

Networks have long been key elements of economic activity but the composition of the goods and services transported has expanded over time. During the Industrial Revolution of the 19th century canals, and later rail networks, transported the raw materials such as coal, wood and agricultural products which entrepreneurs used as tools to fuel the period of intense innovation and economic growth (Turnbill, 1987).

Later in the 20th century much of the freight shifted away from canals and onto rail networks and rapidly expanding road systems. These later two networks allowed more precise shipping of cargo from the source of the goods all the way to where they were used as final inputs and then directly to consumers. Canals had a very narrow footprint which limited the potential destinations for goods but the development of wide-spread road networks greatly expanded the number of potential sources and destinations of transported goods. Innovations were not linked solely to the transportation of raw materials. Improved road networks opened up the possibility of travelling by car and spurred the development of cities and industries (motels, fast-food restaurants) along the routes of major roads, effectively creating new growth sectors.

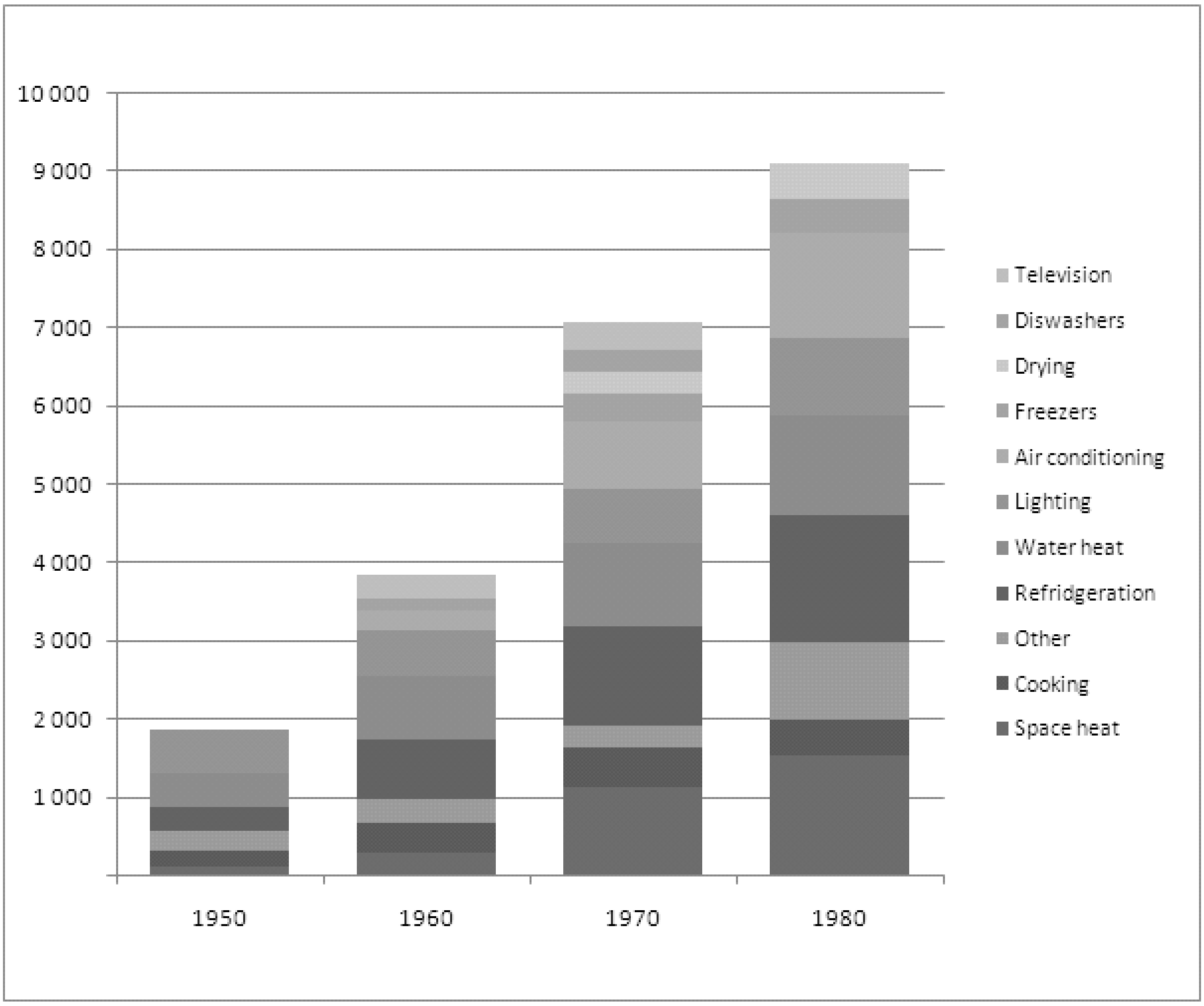
The 20th century also witnessed the widespread electrification of societies, allowing for more efficient production across an entire country and shifting how most items in the economy are produced. The rollout of national electricity grids was a large boost to innovation and economic growth and led to monumental changes in economic organisations (Lipsey *et al.* 1998).

Lipsey *et al* explain that there were relatively few uses for electricity when the networks were first built but that electrification quickly transformed techniques and locations of production such as the physical layout of factories. The earlier steam-driven systems required a system of pulleys and belts throughout a factory to power machines. Due to heavy friction loss of the belt systems, the machines needing the most power had to be physically located closest to the central drive shaft. The introduction of electricity changed that by allowing the factory manufacturing segments to be re-arranged to accommodate the flow of production rather than the equipment's power requirements. This turned out to be a key innovation boosting productivity (Lipsey *et al* 1998; (Crandall and Jackson, 2001).

Electricity had a rapid and powerful impact on innovation in consumer markets as well. In the American experience, a policy focus on driving electrification to rural areas during the Great Depression delivered dramatic results. In 1930, only 10% of rural American homes were connected to the electricity grid, but by 1939 this had expanded to 25%, and by 1950, coverage was almost universal.

The chart reproduced in Figure 1 is extracted from a detailed United States National Research Council 1986 study into electricity's role in productivity and economic growth. It demonstrates graphically not only the growth in average consumption of electricity between 1950 and 1980, but also the development of entirely new sub-categories of consumption (innovation) which developed over this period.

Figure 1. Average residential electricity consumption by category, 1950 – 1980, kWh



Source: OECD adapted from "Electricity and Economic Growth", Committee on Electricity in Economic Growth, Energy Engineering Board, National Research Council (1986).

The report observes that over half of the increase in consumption between 1950 and 1960 arose from water heating, refrigeration, and televisions. In the case of refrigeration, technology innovation (frost-free refrigerators and home freezers) was the key driver, while television as a mass market was an entirely new industry, though one arguably built on the development of radio as a mass market, itself an earlier beneficiary of rural electrification. Similarly, over half of the increase observed between 1960 and 1970 was attributable to the penetration growth of electric space heating and air conditioning, both nascent markets in the 1950s, which went on to see mass adoption and continued to be among the top drivers of consumption in the 1970 – 1980 period.

Thus, the existence of infrastructure to generate and distribute affordable electricity to the majority of American homes kick-started cycles of innovation which created entirely new segments of consumer demand for products and services. This demand was satisfied by the formation of entirely new industries, each requiring its own infrastructures and networks for production, distribution, marketing, installation, maintenance, consumer finance, insurance, etc. Many of these new industries required partners and suppliers in ancillary industries, of which many were, themselves, newly created. Table 1 provides a sample of new, innovative products created after 1970 which rely on the electricity grid to function.

Table 1. New electronic devices introduced after 1970

Personal computers	Broadband modems	Peripheral hard-disk drives
Printers/scanners/FAXs	Wi-Fi routers	Digital cameras
Set-top boxes (cable/satellite/IPTV)	Digital/satellite radio receivers	Digital video cameras
Personal video recorders (PVRs)	Motion sensors	Home health monitoring equipment
DVD players	Chargeable peripheral devices (Bluetooth headsets)	Electric vehicles
Game consoles and their peripheral devices (*e.g.*, Guitar Hero)	Chargeable communications devices (mobile phones, laptops, netbooks)	Chargeable storage and entertainment devices (portable mp3 players, portable video players, portable game consoles)

Undoubtedly, this list is incomplete, but its intention is to illustrate the wide range of now commonplace household items arising from innovation fostered by the existence of an underlying electricity infrastructure. Many of these items would have been viewed as inconceivable to the consumer of 1970.

The perspective offered by history allows us to appreciate the vision of earlier generations in promoting the development of a robust electricity grid available to all, though it is unlikely that this vision would have ever extended to the types of devices and services familiar to us now. From this perspective, it could be argued that the economic and societal benefits of electricity as a general purpose technology have been many times those envisaged by the original advocates of electrification, and that applications for electrical power have evolved in unpredictable ways.

Communication networks supporting the Internet age

The raw materials of the information economy of the 21st century are communications, digitised knowledge, bandwidth, and processing power. Communication networks and the Internet have, in some ways, allowed for a similar transformation of production methods to that previously seen with the introduction of electricity in factories and the subsequent rearranging of equipment to follow the flow of production.

Just as electricity allowed businesses to re-arrange their productive segments within a factory, broadband networks allow businesses to rearrange production globally to take advantage of production efficiencies in different geographic locations. For example, high-speed data lines allow companies to place internal divisions in different geographic locations which are best suited to their factor needs. For example, corporations with large data storage requirements now can build data centres close to inexpensive renewable energy sources in remote areas to take advantage of the renewable energy resources. These remote data centres are then networked to other parts of the company via fibre-optic lines allowing for data to be retrieved from low cost processing areas and delivered anywhere in the world. The effects can be local as well in cases in cases such as teleworking where employees can work from home or local telecommuting centres and still access company resources.

This disaggregated model of production for data-intensive firms has been particularly beneficial as the electricity supplies devoted to servers and data farms doubled between 2000 and 2005 in countries such as the United States and market participants have looked for more ecological solutions. By some estimates, the energy used by servers and data centres in the United States consumed 61 billion kilowatt-hours (kWh) in 2006 representing 1.5% of total electricity consumption in the United States at a total cost of USD 4.5 billion (US EPA 2007). Locating near to inexpensive and environmentally-friendly electricity sources has helped firms with very large electricity demands to expand their services more quickly and in an environmentally considerate way. In this sense, high-speed communication networks help address a key issue in the electricity sector.

Broadband is an important platform which improves access to global resources via high bandwidth communication. Broadband access transformed a number of sectors by making outsourcing and offshoring more efficient. Offshoring of computer-related work started as early as the 1980s when OECD countries shipped audio tapes and paper documents to countries such as India and the Philippines for transcription or digitisation. The process is now much more efficient thanks to high-speed data networks criss-crossing the globe which can transfer documents to be transcribed in seconds, rather than days. (OECD 2006a). The Internet has given us the ability to transmit voice, video, graphics and large volumes of digitized data nearly instantly, and at close to zero marginal cost (Harris, 1998).

Bandwidth and scalability requirements

One of the questions pondered by network planners and policy makers is precisely how much bandwidth is enough to support innovation. This may not be the appropriate question though given how difficult it would be to predict bandwidth demands 10 or 20 years ahead. Instead, policy makers and networks planners should focus on developing a broadband platform which easily supports capacity upgrades to match the bandwidth demand of new applications as they appear. Bandwidth constraints should not inhibit innovation.

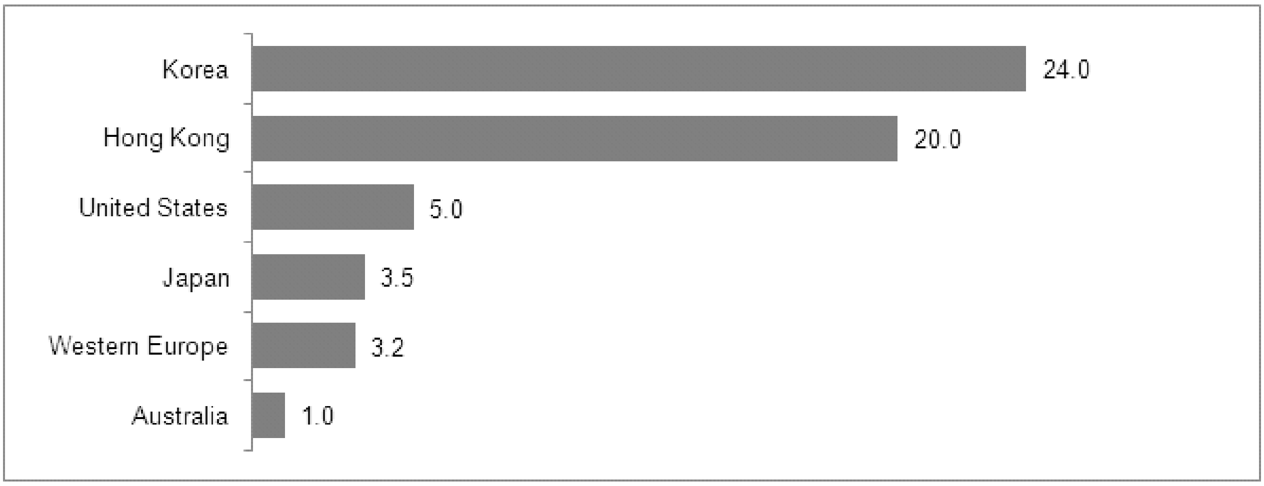
Bandwidth demands from current applications alone such as high-definition video are projected to quickly saturate current broadband networks without substantial upgrades. But broadband demand is not limited to high-definition video delivery. Many new innovative applications and services will need expanded bandwidth to operate efficiently. For this reason, there may be a governmental role in the extensive investments needed to upgrade existing next generation high-bandwidth networks, particularly in areas which may be non-economical for existing operators. These investments are taking place in the context of the economic stimulus packages and, in the longer term, can help improve the efficiency and productivity of the economy in previously unrelated sectors.

The demand for bandwidth has grown roughly 50-60% per year and Internet traffic per capita is significantly higher in some OECD countries than others (see Figure 2).[2] Economies at the cutting edge of broadband usage can provide a glimpse into the types of usage characteristics that many OECD countries will face in the next two to five years, assuming current networks can support future demands.

Fibre-based broadband investments, however, are built to operate at least the next 25 years so the technological decisions facing firms now will have an impact for decades. Network planners need to ensure that the networks they put into place are as forward looking as possible (OECD, 2009b).

Figure 2. Year-end 2008 estimates for monthly Internet traffic

Gigabytes per capita



Source: MINTS at http://www.dtc.umn.edu/mints/home.php.

Some commentators have suggested that the appropriate policy response when laying groundwork for innovation is to "overshoot" estimates of bandwidth demand, particularly because our vision of future applications is limited.

The investment perspective issue

Private view – Market value

Private firms look at the potential returns of any investment under consideration and only undertake the investment if the market value of the investment exceeds its costs. This is a fundamental characteristic of how markets allocate scarce capital. The estimation of the market value of the investment does not include any social benefits or spillover effects unless they can be monetised by the operator (*e.g.* charging a user to access a secondary service which provides benefits to the user).

Telecommunication operators have tried to monetise some of these benefits with varying success (OECD 2008b). In some ways the debates over traffic prioritisation / network neutrality have been over how telecommunication operators may be able to monetise the benefits of using broadband connections for second-party services (OECD 2006b). In other cases, operators have been able to capture some of these benefits by, for example, charging additional fees to mobile subscribers if they want to use their subscription's "unlimited" data connection on a computer tethered to the handset with the subscription.[3]

Therefore, the market is efficient at allocating scare capital to the telecommunication projects which have the highest value, assuming that telecommunication operators are able to extract payments for certain spillover effects to recover the high fixed costs of building out their networks

Telecommunication firms must take on long-term risks with their investments that may not pay off because of the high up-front costs of building out new networks. The result is firms build out networks first in areas where the potential returns are higher. They stop extending networks as soon as they reach areas where their private return on investment is not high enough to cover buildout costs.

High-density population areas are typically the least-expensive for telecommunication firms to wire or cover with wireless signals. The costs of building a network to residences in apartment buildings, for example, can be less expensive than installing the same network in a suburban area with larger distances between homes. On the wireless side, a cell tower in a metropolitan area can potentially cover many more users than the same tower installed in a rural or remote area. Therefore, the return on investment is more favourable to operators in metropolitan areas. Rural and remote areas are usually not cost effective for telecommunication operators and most would be unwilling to extend networks to these areas without government intervention in the way of subsidies or mandatory coverage requirements. Given the high costs of rolling out new networks, markets may not be able to sustain multiple infrastructure providers, resulting in non-competitive provision particularly in less-dense areas (OECD, 2008b).

Public view – Social value

Currently, broadband networks are still built based on the potential private returns to telecommunication operators but the social impacts of broadband connectivity could be potentially much larger than the private returns the operator is able to internalise. This leads to situations where the total benefits of installing a new network outweigh its costs but the network is not built because the operators could not recoup their initial investment. Economists consider this a form of market imperfection that can lead to non-optimal provisioning of services (OECD, 2009b)(Farrell and Klempere, 2006).

Widespread, high-speed network connectivity could have a significant impact on sectors such as health, education, transportation and electricity by improving efficiency and laying a foundation for innovation across these as well as all other sectors of the economy. The cost-savings in other sectors of introducing allowing previously “silent” devices to communicate over broadband networks could help justify investments in these new communication networks.

Policy makers understand the importance of these spillovers and government leaders have committed to promoting the extension and upgrade of broadband networks to benefit from these spillover effects. In the OECD’s Seoul Declaration for the Future of the Internet Economy, Ministers agreed to ensure broadband networks attain the greatest practical national coverage and to stimulate investment and competition in the development of high capacity information and communication infrastructures. Governments made these two types of support a priority – even before the 2008-2009 economic crisis came into full perspective (OECD 2009a).

The recent economic crisis and emphasis on fiscal stimulus spending have opened the possibility of governments directing investment to building broadband networks. These types of interventions are not new because telecommunication markets have faced a similar challenge before with ensuring a national/universal rollout of PSTN and mobile networks. Many governments have imposed universal service requirements on operators along with funding mechanisms which help subsidise PSTN network rollouts in unserved areas (OECD 2005a). Regulators have also attached coverage requirements and buildout timelines to spectrum licences to achieve the same result.

Now that governments are investing stimulus money into broadband networks it is important to examine the size of spillover effects which would be required to justify national rollouts of a new national fibre-optic broadband network. It is worth clearly noting that access to high-speed broadband is an important foundation for innovation but there are often social, legal or organisational challenges to taking full advantage of these networks. This could result in broadband having a lower impact in a particular sector than may be possible otherwise. Any plans to invest in broadband could be coupled with initiatives to address barriers to adoption and to ensure a smooth transition from existing service models.

The following section looks at potential benefits in unrelated sectors which can help justify the cost of building a new national fibre network.

EVALUATING NETWORK INVESTMENT BASED ON THE INNOVATIVE/SOCIAL IMPACT

There are several ways to approach a cost/benefit analysis for installing new, high-speed broadband networks to support innovation in the economy. One particularly challenging way is to try and predict the bandwidth demands of future applications and work backwards to determine which network investments should be undertaken today to support them. The difficultly with this approach is that most analysts have not had sufficient foresight to predict Internet market developments even just a few years in advance – let alone two decades away. It is likely that the broadband experience of 2015 will be very different from the broadband of 2010 or 2025 but determining how is a challenging task.

Authors such as Crandall and Jackson (Crandall and Jackson 2001) have approached network investment by estimating the consumer surplus potential of a broadband network to show that future benefits could outweigh the up-front investment.

This paper takes a different approach by considering the costs of building the most forward-looking network possible and evaluating what short-term cost savings would have to be achieved in other sectors, which could potentially use the network, to justify the investment. There is no differentiation between whether the benefits accrue to producers or consumers. The approach is quantitatively appealing because it does not require specific predictions regarding new services or their individual impact on the economy. Instead, it simply shows how much of a cost savings would be required in various sectors to justify the large up-front investment of a new broadband network. The approach implies that either governments are funding the rollout to benefit from the social impacts or that the private sector is able to extract payments which capture the benefits of using these outside services. An example could be telecommunication firms charging an additional fee to boost quality of service for health applications.

New fibre networks put in the ground today will likely still be in service in 20-30 years but the initial network investments will likely be amortised over a much shorter period of 8-10 years. If the costs of building a new network can be recovered over a 10 year period by means of cost savings in other sectors of the economy then governments have an incentive to find ways to encourage rollouts to capture the gains.

An important point to consider with this approach is that there are already broadband networks covering much of the OECD so any captured benefits need to be tied to the incremental benefits arising from the new network which would not have been possible using existing DSL, cable or wireless broadband infrastructures. As a result, the telecommunication network investments considered for this analysis need to be the most forward looking possible in order to capture the most benefits.

This section will begin by examining the potential innovative benefits across a number of sectors resulting from investment in high-speed broadband networks before calculating what percentage of efficiency gains tied directly to the rollout of the networks would justify the telecommunication investments.

Potential spillovers

This section examines potential spillover effects in four important sectors comprising roughly a quarter of GDP: electricity, health, transportation and education. It provides a brief background on the potential impacts of broadband within the sector before analysing potential data requirements on networks for existing/known applications.

Smart electrical grid (Advanced metering infrastructure)

Traditional electricity grids were originally built for one-way distribution of electricity from producers to consumers and it was not possible to send electricity back into the grid from consumers. There was also no mechanism to measure and adjust billing to credit consumers for any uploaded electricity. Now, operators and policy makers want to introduce more flexibility into the electricity grid and to help curb large fluctuations in electricity demand as they consider new electricity investments. Two key goals are moving necessary consumption from peak to off-peak hours (load shifting) and improving conservation and energy efficiency.

Data networks are a key component of smart grids because they provide the communication channel which makes network monitoring, analysis and the conveyance of price signals possible. Smart grids address fluctuations in demand by sending "price signals" to consumers over a data network, allowing them to modify their consumption accordingly.

Data networks will serve as the foundation of new, *smart* electrical grids (advanced metering infrastructure) by addressing an historical information gap between end-users and distributors. Enabling communication via broadband can provide consumers a vision of their electricity consumption in real time as well as the overall supply and demand situation, allowing them to adjust consumption based on price signals. For the electricity provider, the smart grid allows operators to stabilise demand by monitoring and influencing consumption in real time either through technical intervention or variable demand-based pricing. Smart grids also promise to help manage electricity storage throughout the network which could be used to steady demand patterns during times of peak demand. Broadband makes this possible by opening up a communication channel between the consumer and the electricity provider for collecting and reporting very detailed consumption information on a near continual basis. The data demands for the feedback loop are likely to be large.

Background: Smart grids

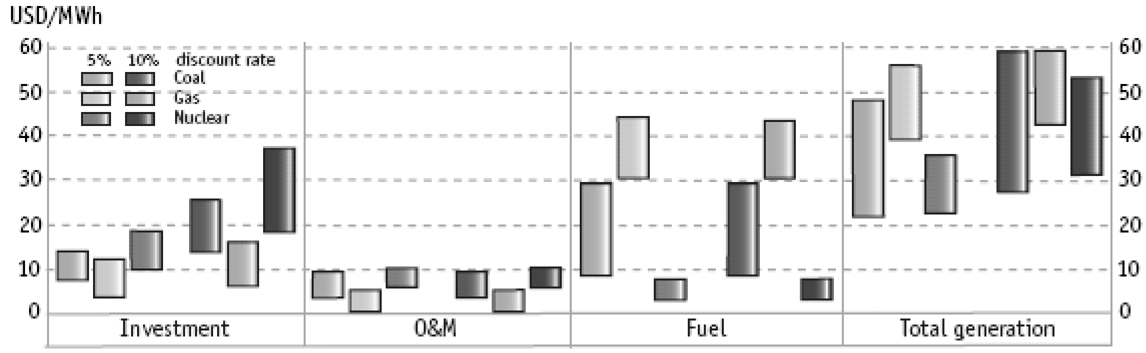
Electricity network operators provision their network capacity to accommodate *peak* use during the year but must also keep the ever-fluctuating electricity supply and demand constantly in balance to maintain frequency and voltage on the lines. This is typically done by giving a system operator direct control over turning on or shutting off various electricity production plants connected to the distribution network (Newberry, 1997).

The lowest-cost plants are run continuously and the network operator selectively turns on or off production of the most expensive plants to accommodate fluctuating demand. Since peaks do occur, the plants with the highest production costs must still be maintained so they can be started with very little notice. Some of these plants are rarely used. In the case of the United States, it is estimated that approximately 25% of electricity distribution assets, and 10% of generation assets, are utilised less than 400 hours per year, during periods of peak demand.[4]

The costs of generating a megawatt hour of electricity can vary significantly between plants. In 2005, the International Energy Agency reported that the normalised costs for various power plants ranged from just over USD 20 to nearly USD 60 per megawatt hour, implying there is a rapidly increasing marginal cost of producing electricity when networks are running at high capacity (NEA/IEA 2005) (see Figure 3). As a result, steps taken to reduce demand at peak periods will have the largest marginal impact on production costs.

Figure 3. Range of levelised costs for coal, gas and nuclear power plants (USD/MWh)

2005



Source: Projected Costs of Generating Electricity, 2005 update: at: http://www.iea.org/textbase/nppdf/free/2005/ElecCost.pdf.

Another challenge for power sector markets (*i.e.* system operators) is to maintain a supply/demand balance on their networks which increasingly use intermittent sources such as solar and wind power. Solar and wind power cannot be relied upon for base load generation because production would be high on windy, sunny days but would fall dramatically on cloudy, calm days. Coal, gas and nuclear power plants have much more stable production properties. Government objectives such as the European Union's "20 20 by 2020" project[5] which aims to have a 20% reduction in greenhouse gasses and a 20% share of energy production from renewable sources by 2020 have made the efficient integration of solar, wind and hydroelectric power into the electricity grid a high policy priority.

Finally, consumers are increasingly installing their own electricity generation equipment based on solar power (and possibly wind in the future) and could potentially upload their excess capacity back to the grid. This distributed generation offers incremental capacity for the power grid without the need for new capital-intensive centralised generation facilities or relatively expensive and inefficient peak load generation capacity. This may involve photovoltaic generation from rooftop solar panels or outdoor arrays, wind turbines (either commercial/industrial or at the home or small business premises), or from plug-in rechargeable hybrid electric vehicles (PHEVs). The latter, in particular, would appear to offer significant gains in capacity and some scenarios suggest that this incremental capacity may be dramatic, subject to the widespread adoption of PHEVs.[6]

There are large potential benefits for the economy if there is a way to smooth out the wide fluctuations in electricity demand. As the marginal amount of electricity is more expensive to supply, reducing the need for high-cost energy plants can generate asymmetrically large cost savings for the consumer, as well as mitigating the need for incremental capital investment by utilities.[7] Informing consumers of their consumption in real time can also help improve conservation, again limiting reliance on expensive production plants at the margin.

Empirical evidence shows the potential economic impacts of smoothing electricity demand are large. Faruqui and Sergici (2009) survey 15 recent experiments of dynamic electricity pricing and find that households do respond conclusively to higher prices by lowering usage. The magnitude of the price response varies based on several factors, including whether there is central air conditioning in the home and the existence of thermostats which can be controlled remotely. Across the range of the experiments they study, time-of-use rates induce a drop in peak demand that ranges between 3% and 6% and critical-peak pricing tariffs induce a drop in peak demand of between 13% and 20%. When there are enabling technologies present in the home such as smart thermostats the critical peak demand falls by 27% to 44% . These reductions can have a significant impact on the cost of providing electricity because they reduce the need to run inefficient production plants.

Electricity producers already take steps to reduce peak consumption with peak-load pricing schemes but these are typically for set times of the day throughout a contract period and cannot be adjusted in near-real time without a communication channel to the consumer. Price signals tied to the cost of producing electricity throughout the day could offer significant incentives for households to modify their consumption schedules by, for example, operating a clothes dryer during off-peak hours.

Cross-sector synergies are one of the reasons energy efficiency is a prominent feature of economic stimulus packages created in response to the global economic crisis. A notable example is the USD 11 billion commitment by the US government to the Smart Grid Investment Program under the American Recovery and Reinvestment Act of 2009 (a figure significantly higher than the USD 7.2 billion allocated to broadband development in the same bill).[8] It is expected that such initiatives have the potential to deliver multiple benefits to economies which invest in them, both in the near term as drivers of job creation, and also in the longer term as catalysts for innovation, industrial development, enhanced competitiveness, and improved energy efficiency.

By its very nature, distributed generation presents the utility with a widely dispersed and highly fragmented pool of resources from which to draw, and this pool requires close and detailed monitoring in real time in order to be managed efficiently. Homes with solar panels or potentially wind turbines may generate excess capacity to contribute to the grid in an erratic manner, subject to weather and other variables. Rechargeable vehicles with excess capacity may be connected to the grid in a variety of locations, so monitoring their locations and mapping this data (and their capacity) against locations where demand is highest is an essential requirement. There is also the need to facilitate the creation of a market mechanism in order to provide contributors with financial incentives such as credits for generation to offset against consumption, or free parking and preferential rates for congestion charging in the case of rechargeable vehicles. All of these activities require broadband connections for real-time monitoring and reporting of key details such as location, capacity available to the grid, capacity required from the grid, performance conditions in the local area or the wider grid, and market pricing trends.

Broadband needs: Smart grids

First generation "smart metering" systems typically feature a wireless transmitter which sends updates on electricity consumption levels over a short distance. The outputs from these meters have been harvested at monthly, or otherwise regular, intervals by utility fleet vehicles driving past the premises. While this removes the pain and cost of manual meter reading, it still does little more than provide a snapshot of aggregate electricity consumption which is not particularly useful for analysis.

A new generation of smart grid solutions seeks to harvest data in real time, which can be analysed in detail by both the utility and its customers, and used to better manage consumption. There are a variety of approaches, but typically this is achieved via a monitoring functionality either attached to, or embedded in, the metering system. This may be networked, typically via a short range wireless technology such as Zigbee with a number of devices, appliances, and smart power outlets in the home or business to track the sources and patterns of electricity consumption. The final piece of the puzzle is a display device, in some cases wireless and portable, which allows the utility customer to monitor current consumption and to analyse granular data in real time (see Figure 4).

Figure 4. Onzo wireless display and sensor

Source: www.onzo.co.uk.

Among existing systems, data harvested from smart meters and associated monitoring systems is typically returned to the utility company using wireless connections, either via dedicated proprietary networks, or existing mobile carrier networks services. Wired broadband could offer another low-cost solution to managing the energy network communication. The increasing presence of wireless femtocells (short-range cellular/mobile hotspots which connect directly to a home user's broadband connection) within the home could offer a valuable return path for data to the utility via a hybrid fixed/wireless broadband combination. It is expected that utilities will employ a mixture of fixed and wireless broadband solutions in collecting data for analysis.

Smart grid investments and technologies are still in their early stages of development so there is relatively little information available about potential bandwidth demands on data networks. GE Energy estimates that its Intelligent Grid applications require a minimum of 100 kbit/s in order to accommodate hourly readings.[9] Some newer proposals have data requirements at 1 Mbit/s.[10] If meter readings and feedback were performed more frequently the data requirement could rise. Another estimate from a utility company suggests that 1 000 000 homes connected to the smart grid may produce as much as 11 gigabytes of data per day,[11] which could pose a significant data warehousing and management challenge to utilities.

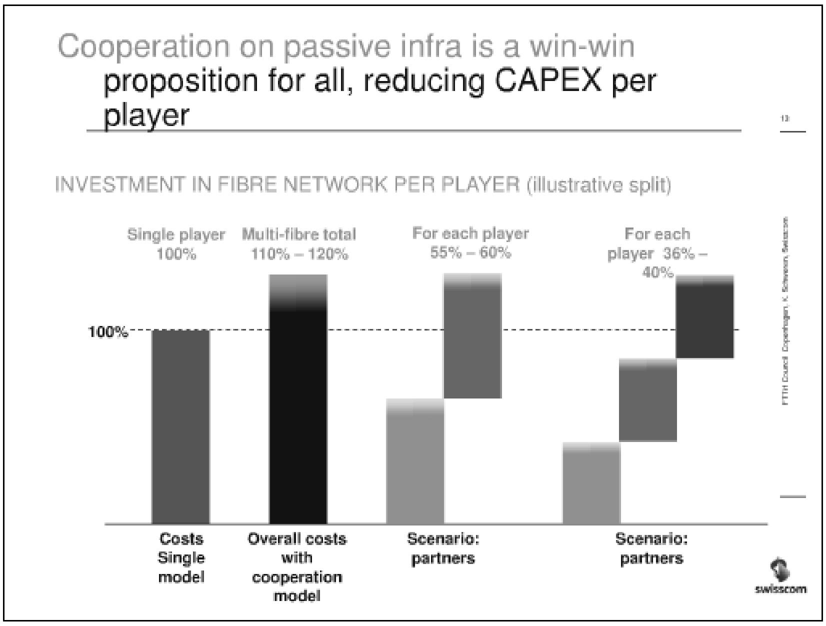
These data requirements could increase significantly beyond 100 kbit/s once households begin feeding electricity back into the network and reporting on the status of equipment. Data requirements could also increase substantially if communications are not sent directly to a clearinghouse but rather broadcast to other customers' equipment to co-ordinate flows.

Bandwidth of 100 kbit/s is largely within the realm of existing broadband infrastructures such as DSL and cable (and many existing wireless networks) for the last kilometre. Bandwidth of 1 Mbit/s, particularly for uploading data, could be more difficult given current asymmetric architectures. Potential bottlenecks will more likely be found in backhaul networks which must transport the aggregated data from a large number of subscribers back to a central location for processing. Backhaul networks are currently provisioned on the assumption that bandwidth demand will be sporadic across subscribers, allowing operators to share the advertised capacity typically between 20 to 50 subscribers or more (OECD, 2008c). Smart grid applications could significantly increase the bandwidth traffic of subscribers and also lead to a constant, higher level of demand across the communication operator's entire network. Again, much of the impact of smart grids on broadband will be tied to how much information is passed between users and the energy company and the frequency of these communications.

Smart grid operators face two important challenges with using broadband networks as the return path for communication with their clients. First, the electricity companies need a communication path to all residences and businesses – not just those with broadband subscriptions. Second, relying on a home broadband network (without quality of service guarantees) for commercially important communication has some key drawbacks. For example, the electricity provider relying solely on one broadband connection would not be able to pass data to a customer if there was a line fault or during times of scheduled maintenance. Electricity companies have been reluctant to entrust an outside carrier to manage this communication and have looked often to broadband-over-powerline (BPL) solutions instead which they manage themselves. Previous OECD research found some ISPs using BPL have actually retreated from marketing broadband and focused on smart-energy applications instead (OECD, 2008d). Electricity networks are viewed as critical infrastructure in the economy so ensuring a data path to monitor the network with very high quality-of-service guarantees, potentially over a dedicated fibre, is particularly important.

Given the impact of electricity on the economy it is important for policy makers, electric companies and telecommunication firms to find ways to work together to achieve common goals and reduce costs. In the United Kingdom, the Broadband Stakeholders Group found that building a national fibre-to-the-home network could be less expensive if undertaken by a utility company (capitalising on existing infrastructure) than if installed by one of the large telecommunication operators (UK BSG, 2008). In Switzerland, the key telecommunication providers have partnered with electric companies to install multiple fibres to each residence throughout the country. The rational is that by mutualising the civil works across carriers the cost for each operator is significantly less than if they each installed their own single line (see Figure 5). In the Swiss model, each provider who is building a new network lays one fibre optic cable containing multiple fibres inside. The unused fibres are then offered to interested operators for sale or exchange, such as for dedicated use by the electric company.[12] In this sense, once a building is wired by one operator there are available fibres for the other market participants.

Figure 5. The Swiss model for the mutualisation for fibre installation



Source: Swisscom.

Partnerships between electricity companies and telecommunication operators could be beneficial for a number of reasons. First, electricity providers are reluctant to use existing consumer broadband networks to manage critical smart grid services because they would rather remain in full control of the communication. To this end many are beginning to invest in developing their own stand-alone wireless/fixed networks to carry the traffic securely. However, as the Swiss model implies, the cost of building two parallel networks (without co–operation) is significantly more expensive than if all market participants mutualise the digging and installation of multiple fibres to each home. The incremental cost of laying the second, third and fourth fibres to a home is negligible as long as they are installed at the same time. Under such as scenario the electric company could manage its own secure data network to all households, not just those subscribing to broadband while broadband providers would have their own lines to offer consumer and business data services.

The Swiss model also promotes infrastructure-based competition by letting operators control their own individual fibre. There are significant benefits to innovation when operators have full control over a physical line and are able to introduce new service offerings without constraints. It is not the only solution though. Other solutions exist such as using virtual local area networks over existing data connections or using multiple wavelengths across the same fibre as a way to separate services.

Wireless networks will also retain a key role in supporting the development and rollout of smart grids. Wireless networks paired with fixed connectivity could provide important redundancy for communications between subscribers and the electricity company. One concern with wireless broadband solutions is that the amount of data traffic from the smart-grid traffic alone could significantly reduce the amount of bandwidth available for other services. Therefore, it is important that fibre backhaul networks reach cell towers to support as much wireless capacity as the air interface will allow. Broadband over powerline will also likely remain an important feedback channel, although it will be much more limited in terms of bandwidth than a fibre-based return path.

E-Health

Background: Health

Health systems are facing tremendous pressure to improve health quality, accessibility and outcomes, and to do so in a cost-effective manner. Broadband supporting information and communication technologies in health offers great potential to address these challenges (OECD, 2004a).

There is widespread agreement regarding the quality benefits that might derive from widespread adoption of information and communication technologies in the health sector. Health ICTs are increasingly seen as part of an inevitable process of modernisation of the health care system. The technology has progressed significantly and many estimate that ICT implementation can result in care that is higher in quality, safer, and more responsive to patients' needs, and at the same time, more efficient (appropriate, available, and less wasteful). Advocates, in particular, point to the potential of ICTs to enable health system transformation. Recognising this potential, many OECD governments have issued nation-wide strategies, set targets, allocated significant resources and established co–ordination bodies to promote widespread use of ICTs in the health sector.[13]

E-health applications have been discussed and promoted since the arrival of residential Internet access but the implementation progress has been slow. By some accounts there may be a new momentum building. In Europe, e-health is considered a newly emerging industry in the public health sector (Murero and Rice 2006) and by 2010, spending on e-health is expected to correspond to 5% of the total of national health budgets – a considerable increase on the 1% recorded in 2000 (Watson, 2004).

High-speed data connections have been the foundation for e-health applications and the field of radiology was one of the earliest beneficiaries. Digital versions of radiological films, which are very large in size, are transported over high-speed data connections where they can be viewed and analysed by remote radiologists. Dermatologists are also increasingly using tele-dermatology in a similar fashion. Broadband networks allow staff in remote clinics to take a picture of a rash, for example, and transmit it to a dermatologist along with a patient history for diagnosis and treatment recommendations (Maheu *et al,* 2000).

There are specific examples where tele-health services have addressed specific needs well. Sweden's advanced communication platform for health care, Sjunet, has allowed Swedish hospitals to find innovative solutions to specialist shortages in local hospitals by using the Internet to send radiographic images to radiologists located abroad. When the radiology department at Sollefteå Hospital was unable to recruit a magnetic resonance imaging (MRI) specialist they decided to use the communication network to send high-quality images from Sweden to a telemedicine clinic in Barcelona for analysis. Once the examination is done by radiology nursing staff the images are sent to Barcelona and the response from an MRI specialist arrives within 48 hours. Outsourcing the reading of some of these scans in Sollefteå helped reduce the waiting list for examinations (Larson, 2003).

The World Health Organisation's Electronic Health Care Delivery (eHCD) programme has also promoted broadband as a way to improve communication and interaction between primary care providers in communities and relevant specialists. These new communication channels can help reduce the professional isolation of community health practitioners by having them actively participate in remote procedures such as tele-cardiology (founded on the exchange of digitalised EGC, digitalised echocardiology or digitalised stethoscopy) and tele-radiology, based on the exchange of digitalised X-ray images.[14]

High-speed data connections initially provided important communication links only between large hospitals and then later extended connectivity to outlying clinics. Now as residential broadband penetration rates are approaching saturation points in some OECD countries there is potential for more doctor-to-patient interaction between hospitals/doctors and end-users at home. Two specific areas where broadband will likely have a significant impact in e-health are increasing the efficiency of health monitoring and reducing the costs on the system via remote consultation and intervention.

Tele-consultation is one of the most challenging innovations to put into practice but there have been successful trials using home broadband connections. The University of Minnesota in the United States piloted a home health care service in both urban and rural Minnesota which used low-cost, standards-based telecommunications and monitoring technologies for homebound patients needing skilled home health care. The telecommunication equipment used for the study consisted of an Internet connection and a set-top box which was connected to a camera, a television set and a phone line. The trial wanted to address the difficulties patients and their families face travelling for follow-up visits when home services were not available. The study focused on three clinical areas that typically employ significant home health care resources: congestive heart failure, chronic obstructive pulmonary disease, and chronic wound-care. The study found tele-homecare to be a cost-effective method for delivering services to those with medical access problems and that patient satisfaction increased significantly among those who had home health care plus virtual visits using the telecommunication system.[15]

The success of the trial in Minnesota led to the introduction of similar technologies in nursing homes in rural Minnesota which allow staff to consult with area hospitals to determine whether nursing home patients should continue receiving care at home or whether they should be transferred to the hospital (Murero and Rice, 2006).

The arrival of telemedicine and e-health applications could also reduce the loads on hospitals, saving them time and money. The World Health Organisation suggests that tele-consultations can reduce the need for patients to attend hospitals, allowing hospital staff to then focus their resources on patients who may benefit from treatment at the secondary level of health service.[16]

Momentum is also building for co–ordinated tele-health solutions among industry groups. Continua Health Alliance, a non-profit organization comprised of over 180 member companies from the pharmaceutical, healthcare, technology and telecommunication industries focuses on three broad targets for tele-medicine: fitness monitoring, chronic disease management, and independent living for the elderly. While there may be a high degree of overlap across the three in some cases, the individual use cases for each are somewhat different, though the general vision is consistent: a variety of networked sensors, monitors and other appliances may be employed to perform medical telemetry, to monitor activity levels and personal safety, to allow remote consultation with dieticians, personal trainers and doctors, and to enable various interventions ranging from reminders to take medication to switching off appliances accidentally left on.

There may also be significant synergies with the type of applications envisaged in the Smart Grid, wherein networked devices and sensors within the home look to increase efficiency of energy consumption through intelligent monitoring, reporting, and analysis. One study carried out in Japan in 2005 used an analysis of electricity consumption patterns within the home of an elderly person living alone to infer activity patterns while at home, as a non-invasive strategy for monitoring well-being.[17] Indeed, if compatible network interfaces and software APIs are employed in both Smart Grid deployments and home/healthcare monitoring for the elderly, the information synergies arising should spur a variety of new and innovative features and applications for both.

Broadband has also become a key source for medical information for doctors and patients alike. The National Institute of Health in the United States has developed a repository of lectures on global health and prevention called Supercourse. The Supercourse network includes 65 000 scientists in 174 countries who make 3 712 lectures in 31 languages freely available on the Internet.[18]

Finally, broadband is expected to play a key role in supporting the increasingly older populations in OECD countries as the percentage of the population over age 65 rises significantly. The UN reports that the population growth rate for people over 60 was 2.6% per year, vastly greater than the 1.1% registered for the world population as a whole, and the faster relative growth rate of the older population is expected to continue until at least 2050, by which time those over the age of 60 will outnumber children for the first time in history.[19] One other noteworthy observation of the UN study is that by 2050, the potential support ratio, defined as the ratio of persons 15 – 64 to those 65 and older, will have fallen from 9:1 in 2007 to only 4:1.[20] This is significant in that the potential support ratio serves as a proxy for the number of potential employees whose earnings will fund the social security, healthcare and pension systems necessary to support this significantly larger proportion of older population.

Beyond the economic ramifications of a much lower potential support ratio by 2050, there is also a significant implicit logistical challenge posed by a larger proportion of older population – namely, that there will be a smaller workforce to care for it,[21] and that a significant number of older persons will live alone. A 2005 study by the UN found that, in more developed regions, one-quarter of older persons lived alone, versus only 7% in less-developed regions. For example, in Europe the proportion of older persons living alone was 26%, but for Asia, Africa and Latin America, where multi-generation households are more common, the proportions were 7%, 8% and 9%, respectively.[22] It may be reasonably expected, however, that as these regions develop further and move to more individualistic lifestyles, with lower birth rates and a growing proportion of older population, the percentage of older persons living alone should trend more towards that of more developed regions. Such change is already evident in Japan, where in 1990 the percentage of women 65 or older living alone was only 1.5%, though some estimates state that this figure may be nearly 20% by 2010.[23]

Broadband will play a key role in helping spur innovation in health care delivery which will address some of the key challenges facing OECD countries. It is not, however, a solution in and of itself. Some of the greatest challenges in delivering e-health care are not technology or network related but rather tied to social and legal questions surrounding remote care and these will need to be addressed. The implementation of ICTs is proving a difficult and risky undertaking. Getting doctors and hospitals to adopt ICTs requires overcoming a host of financial, technical, and logistical obstacles.[24] Access to a secure, fast and reliable broadband network will lay a foundation for innovation in the health sector but will need to be coupled with progress with financial and logistical and social obstacles as well.

Broadband needs: Health

Broadband is only one component of a larger investment necessary to support e-health applications and innovations in the health sector. As such, there are several characteristics related to e-health delivery that network designers must consider. These are the reliability and redundancy of network elements, the need for low latency and high-speed symmetric bandwidth, and the ability to have secure communications.

Broadband networks used for e-health services need to be reliable and built with redundancy which can accommodate the failure of a line to ensure the safety of patients. Hospitals are likely to have service-level agreements with their service providers which minimise downtime of the network and provision for a redundant connection in case there are network faults. These higher-quality lines often are available to community health centres in rural areas as well. There are, however, rural health centres which may only have broadband connections which are comparable to home services – without a service level agreement or with no broadband connection at all. Residential broadband subscriptions typically come without quality of service guarantees. One way to address this is by using a wired broadband line for the primary connection and a secondary line (either wired or wireless) as a contingency backup connection.

Health applications can also require very high levels of both downstream and upstream bandwidth to function correctly. Videoconferencing software often used in other sectors provides lower quality video than a television would provide because the video component is often a secondary priority to voice. In the health sector, a doctor's prognosis of a patient is often very much tied to visual cues and examinations which require a much higher video quality. In Sweden, Sjunet's operators found that normally a 10–100 Mbit/s connection was sufficient for most applications (Larson, 2003).

Since health interactions require communication in both directions it is important for the connections to accommodate high-bandwidth symmetric connectivity. High-definition video over broadband promises to improve the interaction between patients and remote doctors but the systems require more upload bandwidth than current DSL and cable broadband networks are generally able to provide. It is generally believed that health applications will require symmetric bandwidth (Tan, 2005). One of the key challenges facing e-health providers is that the remote centres which will be uploading many of the large files to specialists in larger cities are precisely the institutions which need the fastest upload bandwidth but in reality, often have the slowest available connections.

Figure 6 provides a breakdown of estimated data speeds required for certain e-health applications, broken down by institution size.

Figure 6. Bandwidth needs for health applications

Estimated Quality of Service for Selected Applications & Bandwidth Classes

Application Professional E-Health	**Application Technology**	**Individual**	**Small Institution**	**Large Institution**
		10 Mbps	100 Mbps	1 Gbps
High-quality non-real-time video-imaging for diagnosis	File transfer	High Quality	High quality	High Quality
Cardiology neurology and emergency room consultations	H.323 video	High quality	High quality	High Quality
Cineo-angiography and Echocardiograms	H.323 video	High quality	High Quality	High Quality
3d Interactive brain imaging	SGI Vizserver	Unsupportable	Medium Quality	High Quality
Clinical decision-support Systems	Web browsing	High quality	High Quality	High Quality
Advanced clinical decision support systems	Image transfer	Low quality	Medium Quality	High Quality
Professional Tele-education	MPEG 1 video	High quality	High Quality	High Quality

Source: The Next Internet: Broadband Infrastructure And Transformative Applications, CANARIE Inc., 2001

www.oecd.org/dataoecd/16/8/1936586.pdf,

One reality across all telecommunication networks is particularly poignant in the health setting; the network is only as fast as its slowest link. Bandwidth within a city may be large but rural areas will likely have slow connections. For telemedicine to be practical and efficient the telecommunication lines need to be able to support high-bandwidth services and applications along the entire connection path. Any slow links within the network will limit innovation and the rollout of new services to all areas. In addition network infrastructure should take into account forecasts of future capacity demands (Latifi, 2008).

Because these networks directly support a patient's health there needs to be a qualified infrastructure and communication network capable of delivering data error free and on time by the use of minimum thresholds for parameters such as bandwidth and latency (IFMBE, 2008).

Latency is a measure of the delay of data packets traversing a network. Some health applications such as sending patient records can tolerate a delay between the transmission of packets and their reception at the other end. Other applications such as video conferencing and the remote operation of equipment can only tolerate small amounts of latency before they cease to be efficient or safe. In general, human-to-human interaction over communication networks becomes uncomfortable with anything larger than a half-second lag in speech (OECD 2006b). Therefore, for broadband networks to maximise potential innovation the network needs to be able to support very low latency.

Finally, given the sensitivity of patient data there needs to be security built into any broadband system used for health which will encourage trust in the system, leading to more innovative benefits. Some hospital-to-hospital connections are simply leased telecommunication lines which do not traverse the Internet for security reasons. There are a number of ways to secure sensitive data as it passes over the Internet but health providers may still choose to run parallel networks for an extra layer of protection. Fibre connections between health clinics offer several possibilities for separating health data from general Internet traffic. First, data can be encrypted inside a virtual LAN within existing data streams. Second, health networks could use a different wavelength of laser on an existing fibre to operate a parallel network. Finally, a broadband rollout using multiple fibres could allow health providers to operate completely separated networks.

Intelligent transportation systems

Background: Transportation

Broadband will play an important role supporting innovation in the transportation sector. As an example, broadband networks, both wired and wireless, can improve the efficiency of transportation by allowing much more transportation data to be gathered, analysed and acted upon by commuters. Traffic congestion is a significant problem in cities across the OECD which reduces productivity, increases fuel costs and pollutes the environment. Traffic planners struggle to understand traffic flows because there are no sufficiently robust means to collect traffic data, analyse and model it in real-time and then pass the results along to all concerned drivers, commuters and traffic control systems (*e.g.* traffic light systems). Communication networks and access to the resources they provide form the foundation for collecting and distributing timely information which can then help reduce traffic congestion, lower fuel consumption and help users avoid accidents.

Traffic planners have identified several ways to influence traffic congestion. First, moving people out of personal cars and onto public transportation would have a significant impact on road traffic and the environment. Second, planners can ease congestion if they can help influence departure times, helping to stagger waves of traffic. For example the Irish Workflow Programme uses a wireless sensor network to measure traffic around Dublin and disseminate that information to households to help alter the traffic flow

(OECD 2008e). Finally, a longer–term solution is to change social patterns and have people live closer to where they work. Broadband's largest impact will likely be on the last two items.

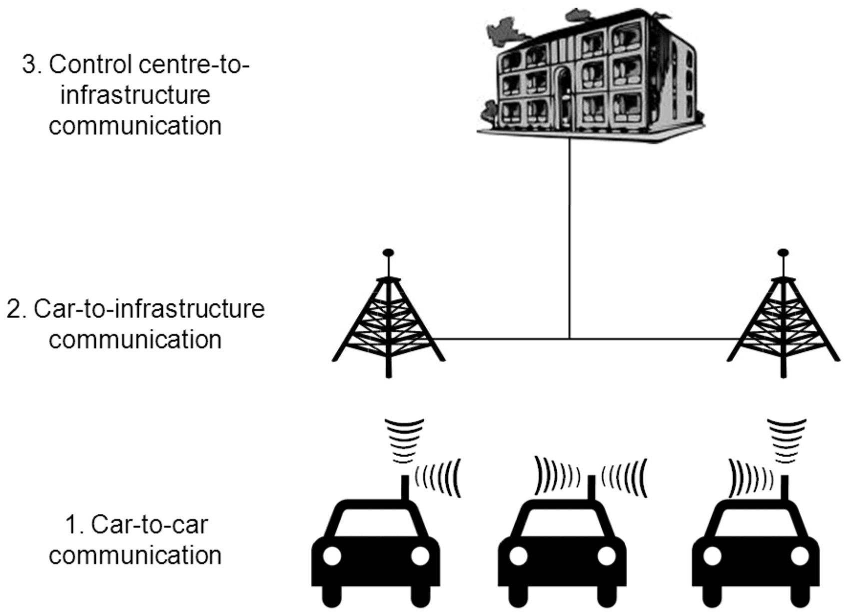
A little bit of relevant information can provide substantial savings to commuters. Having real-time information about congestion on a potential route can save time, money and fuel by allowing travellers to adjust their routes to avoid congested areas. A Motorola study found that 80% of drivers avoided a route if they were notified of construction in the area in advance.[25] Avoiding congestion has a large impact on the economy and the environment because time spent waiting in traffic is lost productivity for the entire economy. In addition, longer commutes mean more fuel consumption and pollution.

Broadband will never be able to completely end traffic congestion but it could be used to minimise it. This is still important because the impacts of traffic congestion are large. The EU estimates that 10% of all roads are affected by road congestion at a cost of between 0.9 and 1.5% of GDP in the European Union.[26] Traffic is projected to become increasingly difficult as well with growth in the EU expected to be 50% in freight transportation and 35% in passenger traffic between 2000 and 2020.[27] Any reduction in idle times also reduces fuel consumption and relieves pressure on national fuel supplies. In the United States in 2007, consumption by the transportation sector accounted for 28% of the total national energy supply and highway transportation fuel consumption, in total, has grown by an average of 1.7% per year since 1970.[28]

Current road transport information systems already provide those who travel in their own vehicles some real-time information on the traffic situation – road construction, weather conditions, congestion and accidents. This information is most typically delivered via radio broadcasts. Most modern European car radios are equipped with the RDS system of traffic news priority. Traffic information is usually transmitted at regular intervals (*e.g.* every ten minutes or after each full hour), during unusual incidents such as major accidents or during severe weather conditions. Permanent traffic news is also broadcast at temporary venues where a significant increase in traffic is expected (*e.g.* for special events, sports activities and cultural festivals).[29]

Proposed intelligent traffic systems represent a significant improvement over current systems by providing much more targeted information to individual commuters. These systems combine sensor and broadband networks to collect and distribute key pieces of traffic information among cars, to roadside infrastructure and then through broadband networks back to traffic planners (see Figure 7). Once analysed, traffic planners could send tailored information back to individual road signs or even individual cars providing routing information or general traffic advice. These technologies promise to save travellers time, money and fuel by helping them adjust their routes to avoid congested areas. The term "intelligent traffic systems" or ITS is used to describe a range of traffic management systems which use information and communication technologies to improve the efficiency of transportation overall.

Communication segments for intelligent road transportation systems



Intelligent traffic systems which use broadband for communication can also be used to provide travellers with other important and relevant information. Variable message signs are used in urban areas throughout OECD member countries for traffic routing (road, bridges and tunnel closures), for indication of parking space availability, and on motorways and trunk roads for speed reduction.[30] These systems are also used, for example, to display alerts in cases of child abduction.[31] Future intelligent traffic systems could integrate more targeted messaging technologies directly into the displays of automobiles or to mobile phones of users in narrow areas adhering to a certain set of criteria.

It is not just travel on the road network which can benefit from better communication tools. Riders of public transport / mass transit often have no efficient way to learn of cancellations or delays in real-time so they can adapt their transportation routes and methods accordingly. Again, relevant current information about a bus delay, for example, could have a significant impact by helping minimise the impact of the delay on commuters and smoothing out the flows across the entire public transportation network. Broadband networks are again important because even short text messages occupy significant bandwidth if sent to thousands of users simultaneously.

These systems are gaining support from national and regional bodies. For example, the European Commission is aiming to introduce a harmonised intelligent transportation system which would provide information on traffic, weather and speed limits. Eventually, many policy makers look forward to a communications infrastructure which can help prevent collisions through car-to-car communications.[32]

There are two important ways that extensive broadband networks could benefit traffic planners. First, broadband provides the communication channel to relay information between travellers and central control centres. Second, broadband is the communication platform making grid/cloud computing resources available to traffic planners. The sheer amount of data could overwhelm traffic planning computers which are used to detect trends and plan alternative routing suggestions. The computational requirements necessary to run real-time analysis could be too large for individual agency computers but the most complex computational tasks could be passed to cloud computing providers via broadband during times of peak loads. Grid and cloud computing applications are discussed in a later section.

There are other important spillover effects which could be enhanced by the introduction of extensive broadband networks alongside travel routes. Broadband, coupled with new sensor technology, can help track containers in transit across the world which minimises risk and improves efficiency. These networks could also play a key role in decreasing bottlenecks at national borders by notifying customs officials of the contents and details of cargo before the transporter approaches the border. The broadband network could transmit estimated arrival times of shipments to the customs area based on current road conditions, helping officials work more efficiently.

Another key innovation in transportation markets which relies on communication networks is the ability to charge access to motorways in a way which better captures social costs. Systems such as Germany's LKW-MAUT toll system use telecommunication networks to effectively charge trucks (lorries) different tolls to travel on Germany's autobahns based on the distance driven, the number of axles and the emissions category of trucks which have a maximum weight of 12t and above. An on-board unit contains a GPS and GSM radio to authorise payment of the tolls wirelessly.[33]

The LKW-MAUT system has 300 toll checking gantries equipped with detection equipment and high resolution cameras which are able to profile for certain trucks or number plates.[34] Improved road-side broadband networks could help improve the transmission of high-definition photos for toll processing and analysis. The German system applies only to large trucks but similar systems are also used to apply tolls to passenger cars.

The city of London applies a "congestion charge" of GBP 8 per day for vehicles entering central London between the hours of 7:00 and 18:00 from Monday to Friday with the goal of reducing congestion in the city centre. London's congestion charging zone also uses camera technologies to read the number plates of cars moving through the centre of the city and verify if the congestion charges have been paid. The innovation of targeted road charging has helped reduce traffic entering the original charging zone by 21% (roughly 70 000 fewer cars per day). In contrast, bus ridership is up over 6% during the charging hours.[35] This effectively helps achieve the first key goal of traffic planners – moving people out of personal cars and onto public transport.

Both examples of toll innovations are supported by a robust telecommunications network to monitor the system and transport data between cameras, toll sites and central offices. A national, high-speed broadband infrastructure, if already in place, could significantly lower the costs of implementing these types of systems in other areas.

Broadband needs: Transport

Both wireless and fixed broadband networks will play key roles in the development and rollout of intelligent transportation systems. Wireless broadband networks (*e.g.* high-speed mobile networks) are already used for certain "vehicle to control centre" communications. General Motor's OnStar system initiates a call back to a control centre and supplies key information such as the latitude and longitude of the vehicle and whether airbags were deployed when sensors indicate there has been an accident.[36] The same system can be used to track, slow down or even disable a stolen car.[37] Systems such as OnStar send small pieces of data infrequently using a dedicated mobile radio and a GPS receiver. Newer intelligent transport systems may need to provide data much more frequently back to the control centre, and thus would need more network capacity in order to function properly. For example, accident avoidance systems need a constant stream of data from all cars in the vicinity in order to monitor distance, speed and risk.

Wired networks will also play a key role in transmitting data from moving vehicles back to control centres via wired infrastructure at the side of the road. Different proposed intelligent systems place different data demands on networks. Any service which requires near-constant transmission of even small amounts of data could easily overwhelm existing mobile data networks because of the sheer volume of communications. Instead, ITS designers may opt for network topologies which install specialised wireless access points at intervals alongside roads to collect data from passing cars to send back to a control centre for analysis. These access points would also transmit localised or personalised data back to cars.

Saturated frequencies would be less of an issue if the cars could use lower power to transmit just to the side of the road or to other cars via a mesh network rather than to a distant radio tower. In this case, an extensive fibre network can reduce the amount of power required to transmit from cars to the nearest data collection point. In addition, aerial poles and fibre backhaul lines commonly run alongside roads and could be tapped to provide needed transmission capacity. Even ITS rollouts which focus on car-to-car communications will need to feed information back to control centres for overall traffic monitoring. These transmissions would likely flow over both wireless and wired broadband networks.

Telework

Finally, the rollout of high-speed, symmetric broadband could significantly increase teleworking and this could have an immediate impact of commuting traffic. Previous OECD research has suggested that removing just 5% of traffic at peak times could substantially reduce or even eliminate rush hour congestion from many cities.[38] As a result, upgrading a broadband network in an area for telework purposes could also achieve certain goals concerning traffic reduction and improving the environment.

E-learning

Background: Education

Broadband could have a significant impact on education and e-learning by improving access to digital learning resources; encouraging communication among schools, teachers and pupils; promoting professional education for teachers; and linking local, regional and national databases for administrative purposes or supervision.

The prospects of broadband revolutionising education were touted extensively at the beginning of the decade but the impact of connectivity on educational outcomes have been difficult to measure. As the OECD report *E-learning in Tertiary Education* (OECD, 2005b) shows, there was an initial belief during the Internet boom of 2000 that students would follow entire courses at universities from abroad without having to incur the expense of living away from home. This failed to materialise and students are mostly still tied to traditional classrooms for at least part of their tertiary education.

The hype during the Internet bubble led to some disenchantment with e-learning as an effective approach for teaching. These disappointments with early e-learning operations have, at least for now, overshadowed some of broadband's potential for providing flexible access to tertiary education, increasing pedagogic innovation and decreasing costs (OECD, 2005b).

There are encouraging signs though that networks, and the applications they support, are having a tempered but significant impact in several areas by making traditional education more efficient rather than by revolutionising education by shifting students directly to e-learning. E-learning modules, when they are used, are often a tool for improving traditional classroom education.

Access to digital learning resources

High-speed Internet connectivity can improve access to online resources and communication tools used in education. This impact appears to be particularly large in tertiary education. The Internet has become a vital repository for information which supplements and, in some cases, reduces the reliance on school libraries.

Previous OECD research identified how the scientific publishing community (scientific, technical, medical and academic) has been at the forefront of building digital content libraries and disseminating information via the Internet (OECD, 2005c). In the past, secondary research was done by searching through abstracts and research articles and making limited physical copies of important sections or pages. Once the articles were digitised the academic journals and bibliographic search engines were primarily available from terminals located in libraries.

But the extension of broadband to consumers now allows students to access research materials from home either via their school's proxy server or by using one of the new bibliographic libraries available to the public such as Google Scholar, CiteSeer or Scirus.

Bibliographic libraries such as Google Scholar allow users to compose keyword searches to locate versions of the document which are publically available for download. The powerful databases behind these search engines also allow for easy tracking of citations, helping researchers and students make important linkages among connected research. Google's project to digitise books throughout the world and make them searchable could also have a significant impact in education. In its current state, Google Books allows people to search for keywords throughout a large library of scanned books and view certain sections of copyrighted works on line. This could have a potentially large impact on research and innovation throughout the economy as access to this library is made more widely available.

Broadband is the key network element supporting innovations such as Google Books which extend access to libraries on line. Measuring the direct benefits of improved access to books is difficult even when it is clear that making books searchable by keywords will have a profound impact on students, researchers and readers.

Broadband helps improve communication and the dissemination of research but it is slowly becoming an important distribution method for classroom teaching as well. Projects such as Carnegie Melon's Open Learning Initiative make full classes available for viewing over broadband, to academic students, instructors and independent learners (see Box 1).

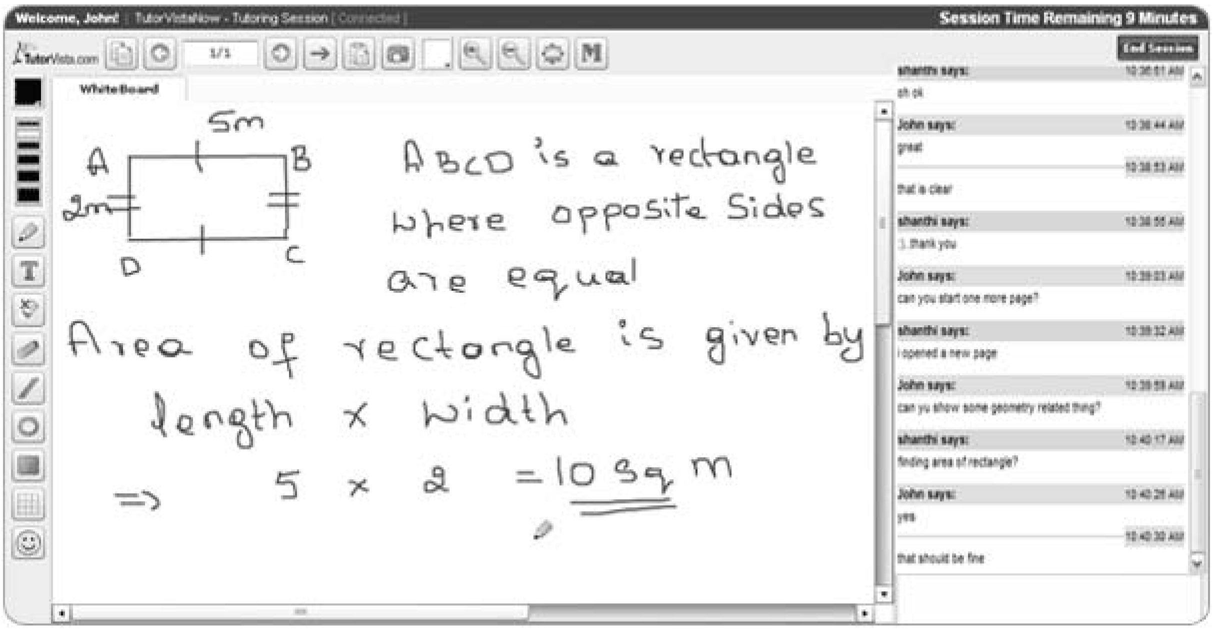
Box 1. Open learning initiative (OLI)

The Open Learning Initiative (OLI) which started in the autumn of 2002 at the US-based Carnegie Mellon University is a good example of the promises of e-learning to enhance the outcomes of learning. OLI courses include a number of innovative online instructional components such as: cognitive tutors; virtual laboratories; group experiments; and simulations. But its specificity lies in the initial development of each course guided by both cognitive theory and faculty expertise. As the courses are delivered, OLI researchers conduct a variety of studies to examine the effectiveness and usability of the learning objects. The research results are then used to improve the courses as well as to contribute to a growing understanding of effective practices in online learning environments. As of July 2009, twelve subject areas are covered at the introductory university level: They are freely available through the OLI Web site: www.cmu.edu/oli.

Source : www.cmu.edu/oli, www.oecd.org/dataoecd/55/25/35961132.pdf.

Broadband networks are also helping students gain access to global tutoring networks. Private-sector tutoring services link students needing help in one country with experts who can help in another. For example, the company TutorVista provides unlimited tutoring over a broadband connection in mathematics, physics, biology, English, chemistry and science to students in the United States and the United Kingdom for a flat rate of USD 99 per month (see Figure 8).[39] The flat-rate fee allows students to have an unlimited number of 45-minute sessions over broadband with tutors in Bangalore, India each month. Some educators are sceptical of the services but they can provide tutoring service prices which are often considerably lower prices than services available domestically.

Figure 7. TutorVista's collaborative distance tutoring service



Source: www.tutorvista.com/howitworks.php.

Broadband is also having an impact on another sector of education – home schooling. Home schooling is when parents teach or have tutors educate their children at home rather than enrolling them in a traditional public or private school. Broadband access opens up access to online learning materials for unfamiliar subjects and provides access to a community of other parents choosing a home schooling approach for education.

Networking among schools, teachers and pupils

The Internet has impacted education by increasing communication among schools, teachers and pupils. An installed base of broadband connections throughout a community makes it easier for school administrators and teachers to interact with parents and others in the community. Broadband access also facilitates communication among instructors teaching the same subjects in different schools and allows them to share lesson plans, ideas and developed course materials.

The Carnegie Mellon Open Learning Initiative (previously mentioned in Box 1) has a component devoted to instructors teaching the subjects covered by the initiative in their own schools. The OLI has course materials available which can be used by other educators. Broadband, in particular, allows teachers to have students complete certain lessons on line using the infrastructure of the OLI, which then provides tools to educators to aid with student assessment.

Professional education opportunities for teachers

Broadband doesn't just facilitate learning by students. It also facilitates the continued learning by teachers, particularly those who may be in rural or remote areas. Broadband provides teachers access to continuing education programmes which may be unavailable in their area and this increased knowledge benefits the teachers' students. Online learning from home is also more effective in terms of time for many teachers who already have a large workload. In this way, high speed broadband networks are not replacing teachers in classrooms but are instead making them more effective.

Linking to databases for administrative purposes

Another area where broadband is currently making an impact on education is by supporting large databases for administrative purposes within school districts. For example, the New York City Department of Education's Achievement Reporting and Innovation System (ARIS) has been linked to improved educational outcomes by allowing educators to view student data, explore instructional resources, share effective practices, and collaborate with colleagues within schools and across the city.[40] The system relies on high capacity broadband lines linking schools back to a central main-frame computer which analyses large amounts of data on students in real time. Parents can also log into the system via their home broadband connections to access the real-time data about their own children in school.

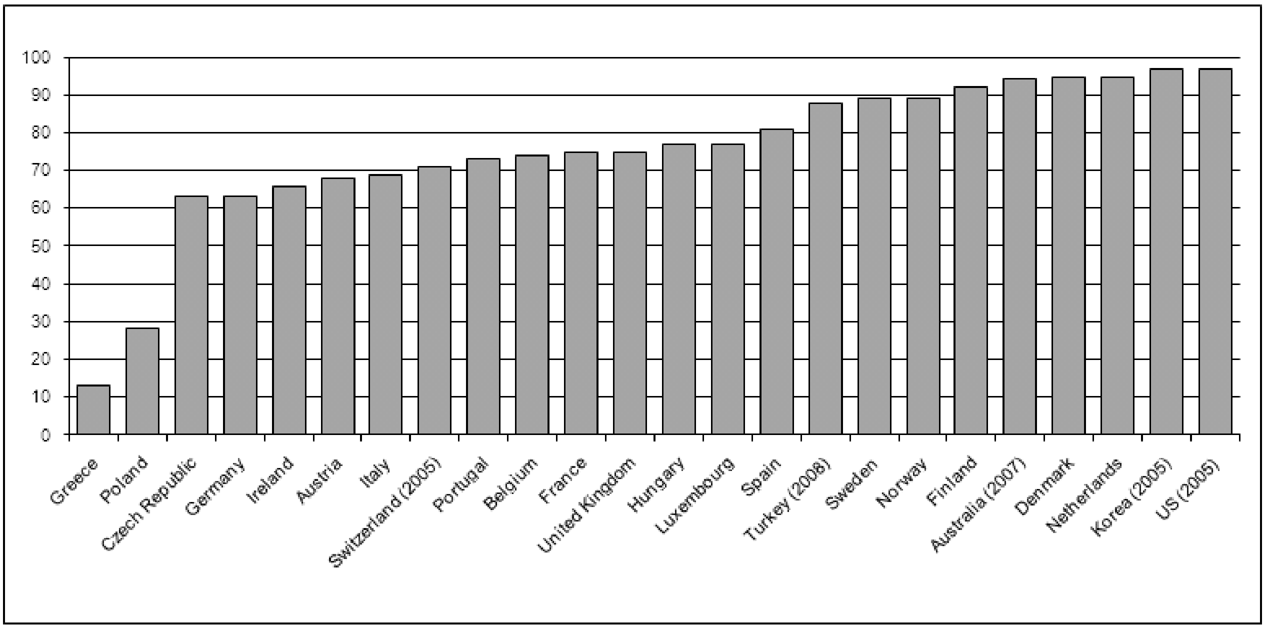
Interestingly, the impact of broadband in the ARIS case is not in replacing class time with online content but rather by helping collect and organise large amounts of data about all aspects of a child's education in a central location for analysis and then redistributing the results to all concerned parties (*e.g.* educators, administrators, parents and the student).

Broadband needs: Education

Broadband connectivity between schools is an important foundation for innovation and learning and most OECD countries have a minimum of 60% of primary and secondary schools connected to the Internet via broadband (see Figure 9). Some countries such as the United States and Korea have reached nearly 100% connectivity while others such as Greece and Poland have much lower penetration rates. It is unclear how much bandwidth is actually available over the lines connecting schools but there is likely a large variation both within and across countries.

Figure 8. Broadband in primary and secondary schools, 2006 or available year

As percentage of all schools



Source: Broadband Growth and Policies in OECD Countries, 2008.

There is very little data on communication infrastructure investment in schools and this makes measuring its impact particularly challenging. Research has typically focused on the broader category of

ICT impact on educational outcomes but investment data is still limited even at this higher level of aggregation.

E-learning typically requires an Internet connection to be delivered effectively in a timely manner. The bandwidth required to deliver content to students can vary based on the types of e-learning projects found across the OECD. In general, e-learning is broken into four categories: web supplemented, web-dependent, mixed mode and fully on line. Table 2 provides a summary of the categories along with an estimate of how much upstream and downstream bandwidth would be required for optimal use in each category.

Table 2. Different modes of E-learning and estimated connectivity requirements

Types of e-learning	Description	Estimated connectivity requirement	
		Download	Upload
Web supplemented	Focus on classroom-based teaching but included elements such as putting a course outline and lecture notes on line, use of e-mail and links to online resources	Low (56 kbit/s)	Low (56 kbit/s)
Web-dependent	Courses require students to use the Internet for key elements of the programme such as online discussions, assessment, or online project/collaborative work, but without a significant reduction in classroom time.	Medium (0.3 - 2 Mbit/s)	Medium (0.3 - 2 Mbit/s)
Mixed mode	E-learning element begins to replace classroom time. Online discussions, assessment or project/collaborative work replace some face-to-face teaching and learning. But significant campus attendance remains part of the mix.	Medium/High (2-5 Mbit/s)	Medium/High (2-5 Mbit/s)
Fully online	Students can follow courses offered by a university in on city from another town, country or time zone.	Very high speed (10 – 100 Mbit/s)	High/Very-high (5-100 Mbit/s)

Source: Adapted from OECD, 2005b at: http://www.oecd.org/dataoecd/55/25/35961132.pdf.

Lower-speed Internet connections are likely sufficient for many types of online learning because web-supplemented learning which involves downloading course outlines or lecture notes is not data intensive. The bandwidth requirements are more important on the download side than upload. Bandwidth demands increase with the more interaction and collaborative work involved.

High-speed broadband is likely required for mixed-mode and "fully online" courses. The video component of courses requires much higher bandwidth than text or audio files. In many cases current OECD broadband speeds are largely sufficient to accommodate the downstream portion of e-learning applications.

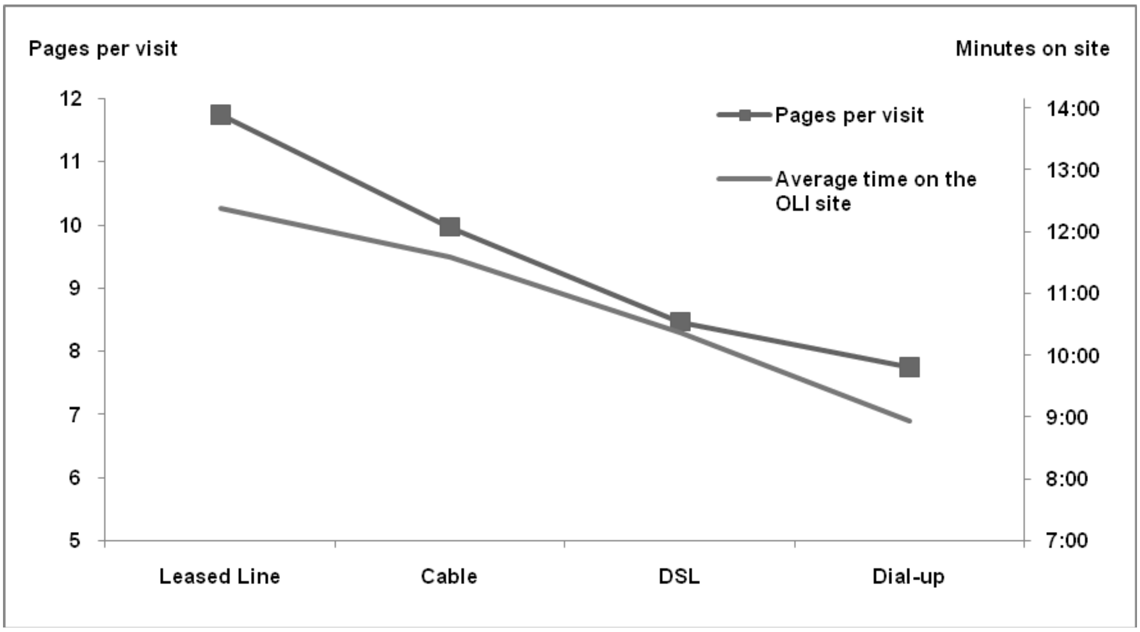
The OECD's 2008 annual survey of broadband speeds and prices shows that the average advertised download speeds surveyed in September 2008 of 10 Mbit/s for DSL, 15 Mbit/s for cable and 65 Mbit/s for fibre are theoretically fast enough to accommodate almost all downstream e-learning. In practice though, actual speeds to the user are much lower than the advertised "top speeds" because an end-user's download speed is determined partially by how many users are sharing the backhaul bandwidth and how far the lines are to their homes from the telecommunication exchange.

The download speeds, as advertised, may be sufficient for most current e-education applications but the upstream capacity is likely too small for others. The demand for new broadband networks (both wired and wireless) will likely be tied to the interactive nature of the courses and will require a faster upload channel than is available on current DSL and cable subscriptions in the OECD. Interactive applications often require symmetric bandwidth to both send and receive high-quality video. In 2008, the average advertised DSL upload speed was only 0.7 Mbit/s and cable was 1.2 Mbit/s, neither of which is capable of uploading even a standard-quality television signal to a learning centre. Only fibre connections with an average upload of 34 Mbit/s offer very high-speed upstream capacity which would be sufficient for high-definition video uploads.

One way to better understand the impact of broadband on e-learning is to examine web-server statistics from e-learning providers. Statistics from Carnegie Mellon University's web analytics software are able to identify the Internet connection type of roughly 70% of all web page views. Where the information is available, the majority of visitors have either cable or DSL broadband connections or access the site through a school (leased line). The data show that visitors with the slowest connections visit fewer pages, on average, and spend less time on the site than those with broadband connections. Cable broadband users spend 30% more time on the site than dial-up users and view roughly 30% more pages (see Figure 10).

Figure 9. CMU: Online Learning Initiative (OLI) statistics on page views and time spent on the site

Breakdown of 273 135 visits positively identified by connection type between 01 November 2008 and 31 July 2009



Source: Carnegie Mellon University Online Learning Initiative.

In some ways the results of the CMU data are counter-intuitive because users with slower connections would need more time to load individual pages and would therefore be expected to spend longer time during their overall visit. The data suggest otherwise and could show that broadband users have a better experience on the site and tend to stay longer and view more pages. Indeed, one of the pages with practice exercises from the Engineering Statistics course can take up to 103 seconds to load over dial-up but only 4 seconds over a fast broadband connection.

Bandwidth constraints force educators and course planners to choose between media fidelity and download times. CMU's French course contains audio and video of native French speakers and, for novice learners, it is important that this audio and video be clear so that subtle differences in the speech can be understood. The CMU media team worked to strike a careful balance between preserving the quality of the content and minimising download times for low-bandwidth users. Having a high bandwidth network reaching users could diminish the need to make such tradeoffs in the future.

In summary, current e-education applications are largely available to students and teachers using existing broadband connections but broadband users enjoy much faster downloads which can lead to a richer learning experience. Application developers have geared current courses and content to be viewed over lower-speed broadband connections and sometimes dial-up Internet access as well. A national high speed broadband network coupled with symmetric bandwidth could stimulate the development of more interactive courses than current upload speeds are able to support.

Wireless networks may also play a key role in supporting existing e-educational applications which are geared to lower-speed connections. The limited capacity of assigned spectrum could limit innovation if sufficient bandwidth were not available to individual users. Educational networks should also have low latency (lag) since applications will likely involve a significant number of person-to-person communications.

ANALYSIS: COSTS VS NECESSARY SAVINGS IN OTHER SECTORS

Costs: National fibre-to-the-home network

The previous section looked at current innovations across four key sectors which rely on broadband to function. This section makes a connection between the costs of rolling out new broadband networks and the impact these networks would have to achieve in these four key sectors to justify the network expansions. This section compares the costs of rolling out a new point-to-point fibre network with the amount of cost savings (spillovers) in electricity, health, transportation and education directly resulting from having a new network which could justify the investment. The analysis modifies a general cost estimate model for deploying a national point-to-point fibre-to-the-home network based on earlier OECD work (OECD, 2008b). Rollout costs vary significantly between areas in practice but setting national coverage as the target allows us to focus on an "average" cost across the economy.

This analysis focuses solely on fibre-to-the-home technologies because upgrades to fibre offer the most substantial bandwidth improvements to existing networks. Certain fibre operators in the OECD currently offer broadband at 1 Gbit/s but these connections could easily be upgraded to support 2.4 Gbit/s and beyond.[41]

There are other significant, incremental upgrades to broadband networks where operators bring fibre closer to end users but not all the way to the premises but these are not modelled in the paper. Examples include upgrades from ADSL 2+ at 24 Mbit/s to VDSL at 50 Mbit/s and cable upgrades to DOCSIS 3.0 which support speeds up to 160 Mbit/s. There is still substantial debate concerning the relative benefits and drawbacks of each broadband upgrade path and policy makers will likely have to consider the costs, marginal impacts and scalability of each of these upgrade strategies.

For the sake of the analysis, the model assumes homes will be upgraded to point-to-point fibre-to-the-home which is viewed as the most flexible, and in many cases the most expensive FTTH option. In terms of innovation, point-to-point fibre promises the most flexibility to competitors, allowing them more potential to innovate since they can take over the physical line and attach the equipment of their choice.

New wireless networks will also play a key role in spurring innovation and providing seamless broadband connectivity to users. These wireless networks will be built largely on top of fibre backhaul networks which supply towers with Internet capacity. A national fibre-to-the-home network would also create an infrastructure to support future upgrades to new, high-speed wireless technology. Wireless networks will not be modelled in this paper because rollout costs for new technologies such as LTE have yet to be determined.

Previous OECD research has looked at developments in fibre technology and investment and provided cost models for deploying fibre-to-the-home (OECD, 2008b). The OECD paper used a model based in the Netherlands to come up with an estimate of passive infrastructure costs in the range of USD 735 (EUR 500) for VDSL and USD 2 206 (EUR 1 500) per household for FTTH point-to-point topologies with an economic write-off period of 25 years. At the time the OECD work calculated the active equipment portion at USD 1 103 (EUR 750), although prices can be lower with bulk discounts and have fallen over previous years.

The Broadband Stakeholder Group in the United Kingdom has come out with similar costs for rolling out fibre-to-the-home. In the report, "The costs of deploying fibre-based next-generation broadband infrastructure" they arrive at costs of just under USD 370 (GBP 200) per household for an upgrade which still uses copper for the final leg of the connection to a users home, FTTC/VDSL. For all fibre rollouts the BSG report estimates the cost of a FTTH rollout using a point-to-multipoint architecture to be USD 1 815 (GBP 980) per household. The costs increase slightly per household for a point-to-point FTTH network at roughly USD 2 037 (GBP 1 100).

Verizon has the largest FTTH network in the United States and it is based on a point-to-multipoint fibre architecture. Verizon estimates their costs per home passed at lower than USD 700 and an additional USD 650-700 for each home connected, for a total of roughly USD 1 400.[42]

The Dutch regulator OPTA has arrived at the price of USD 1 471 (EUR 1 000) per home connected in consultation with operators as part of its tariff regulation for unbundled fibre access (OPTA 2008). Operators will be able to charge between USD 18-22 (EUR 12-15) per month for wholesale access depending on their capital expenditure (CAPEX) profile. Other higher and lower CAPEX profiles can be defined in the future.[43]

The prices to install fibre continue to fall over time. NTT of Japan has the largest fibre-to-the-home deployment in the world and the price of installing fibre lines was eight times higher than copper in 1995 but had reached parity by 2000 (Shinohara and Manabe, 2006).

For this analysis we will use a three "average" installation costs of USD 1 500, 2 000 and 2 500 which are based on the estimates above. These three levels are used to model lower- and higher-cost installations due to differences in geography, density and access to existing passive infrastructure.

Benefits: Required cost savings four key sectors

The analysis requires data on total spending in each of the four sectors in order to calculate the level of cost reductions which could justify the cost of the network rollout based on spillover effects. The data sources provide data on total expenditures which we are then able to convert into household figures. We also provide the spending as a percentage of GDP to provide insight on the relative sizes of the sectors.

Electricity spending

The International Energy Agency (IEA) collects and distributes data on energy prices and consumption which are used to build estimates of monthly electricity expenditures. The IEA Publication *Key World Energy Statistics 2008* (IEA, 2008) provides the necessary elements to build an indicator expressing an entire economy's electricity spending divided across the number of households[44]. The amount of spending from country to country varies considerably depending on whether electricity is a major source of residential heating or not.

All spending on electricity in the OECD is equivalent to USD 296 per month for each household. This corresponds to roughly 4% of GDP.

Health spending

Estimates on health spending are from the OECD Health Committee's publication, *OECD Health Data 2009* (OECD, 2009c). Expenditure data is the last available between 2005 and 2008 and covers both private and public spending.

Health expenditures are one of the largest components of spending in OECD countries and total expenditures through the economy equates to USD 885 for each household per month. This corresponds to just over 11% of GDP across the OECD.

Transportation

Transportation data is from the OECD's Annual National Accounts database and contains household expenditures for operating a personal vehicle or using other forms of transportation. The cost of purchasing a vehicle is excluded. The indicator is built by using the latest data available between 2005 and 2008. Data is not available for Japan, Mexico, New Zealand, Switzerland and Turkey.

In is important to consider that the transportation costs included in this analysis are those made solely by households and exclude spending on transportation by businesses and governments. As a result, the overall spending figure will understate transportation spending throughout the economy and overstate the savings needed to justify a new communications network rollout.

Household expenditures on transportation (excluding purchasing cars) is equivalent to USD 432 per month across OECD countries where there is data. This amounts to roughly 5% of GDP.

Education

Education data is from the OECD's *Education at a Glance 2008* and is derived using reported expenditures on educational institutions as a percentage of GDP, by all levels of education in 2005 and OECD figures for GDP in the same year. Data is not available for Luxembourg or Turkey.

For countries with data, spending on education in the economy is equivalent to USD 423 per month for each household. Similar to spending on transportation, this is roughly 5% of total GDP.

Key assumptions of the model

This analysis requires a number of assumptions which are described below:

- **National dark fibre deployment:** We consider the costs of building a new, national dark-fibre rollout to all households and base our cost estimates on the assumption that the last kilometre will be upgraded for all households. In reality, high-speed fibre networks are already available in some OECD countries as the result of private-sector investment resulting from competitive markets. Any existing fibre networks would decrease national rollout costs.[45] The model does not consider VDSL and cable network upgrades but could be adapted for an analysis of these incremental upgrade paths.

- **Topology (Point-to-point fibre to the home):** The benefits side of the analysis will focus on innovations built on top of broadband networks. Therefore, it is important to model the topology with the most open, flexible architecture which also provides the highest potential bandwidth for future innovation. Point-to-point topologies offer the highest speeds and other pro-competitive benefits but potentially at an additional cost. The cost difference between PON-based and point-to-point networks are relatively minor compared with the potential benefits from allowing competitive operators to take over an entire line. The model also includes some margin for running multiple fibres to each home for smart grid or home health use.

- **Government involvement**: The model assumes there is a mechanism to base investment decisions on the total social benefits of broadband investment rather than simply the private returns to one operator. This could be accomplished by governments directly funding the rollout or by creating a mechanism which would guarantee a sufficient return to private operators or public utilities who build a national, point-to-point fibre network which is available via unbundling to other providers.

- **Interest rate**: The interest rate chosen for financing a FTTH rollout will have a strong influence on the results of the model. This analysis assumes an interest rate of 5% which is the OECD's long-term interest rate forecast for 2017 (OECD, 2009d). The choice of rate is comparable to the rates available to governments looking to support network rollouts by issuing 10 to 20 year bonds. It is important to highlight that telecommunication firms often require a much higher rate of return before they would consider investing in new networks.

- **Amortisation length:** The copper networks used for DSL have been in the ground in some cases for more than 50 years. Fibre-optic lines are the next generation of wired connectivity and are expected to have a lifespan comparable to copper. Despite the long potential lifespan, this analysis takes a much shorter-term approach of 10 years to pay back the original financing of the investment. This approach reduces financing costs and minimises the risk of the network becoming outdated.

- **Breakdown of installation costs:** We have broken the installation costs of a FTTH build into two parts – passing the home with fibre and then making the last connection to inside the premises. The cost of bringing fibre up the road near residences will vary considerably by location. The model looks at three price points bringing a fibre down a road to each home (USD 850, 1 350, 1 850). These three points reflect varying costs of rolling out a point-to-point fibre network across the OECD but lower-cost rollouts are indeed possible. The second charge is to connect an individual residence to fibre from the backhaul connections in the street. Verizon reports that these costs are close to USD 650 per month and slowly declining. These costs would also tend to be more stable across locations so we hold the price at USD 650 for connecting each home.

- **Installation on-demand or installation to all**: One of the questions facing a new national dark fibre network operator is whether to install the last several metres "on demand" or whether to roll out the network all at once to all households. There are important implications for each approach. Smart grids operators may want to use a fibre line to a household to interact with the smart electricity meter even if the occupants do not have broadband services. This would require a network extending to each household. In other cases, the dark fibre operator may do the final installation to homes only when users subscribe to services (reducing up-front costs but requiring a service visit when they do eventually subscribe). The model will look at the cost differences of the two approaches.

- **Take-up rate**: The take-up of services on the network will have an effect on both the financing of the project but also on the potential benefit derived throughout the economy. A higher take-up of broadband leads to higher installation costs but also more spillover effects for the population at large. The analysis looks at three take-up scenarios (25%, 50% and 75% of households).

- **Price of an unbundled line**: The price regulators set for access to an unbundled local loop is meant to reflect the long-run incremental costs of providing access to the legacy copper network. These costs average roughly USD 14 per month in OECD countries for access to a fully-unbundled local loop. This fee has already been internalised by competitive broadband operators using DSL networks and is reflected in the prices consumers pay for broadband access. We assume that the unbundling amount will stay at the copper rate for FTTH networks. The unbundled fees will be used for paying operational expenditures for the fibre and helping to reimburse capital costs.

- **Operational expenditures (OPEX):** The rollout of fibre-to-the-home can significantly reduce operational expenditures (OPEX) on broadband networks and reduce the amount of the unbundling charge which must be used to maintain the line. OPEX costs per line for copper networks are typically around USD 200 per year and FTTH networks have OPEX costs which are estimated to be about half that amount (USD 100 per year, or USD 8.33 per month). We have allocated the full USD 8 per month for line maintenance (although in reality it is likely lower) and have left the remaining USD 6 of the unbundling charge to be put toward retiring the debt of the initial capital investment. One of the key benefits of fibre networks is that they are much more reliable than copper networks and require fewer service calls. One fibre equipment manufacturer claims that FTTH systems have 80% less trouble calls than similar DSL networks. These cost savings show up in operational savings which can be used to pay down debt.

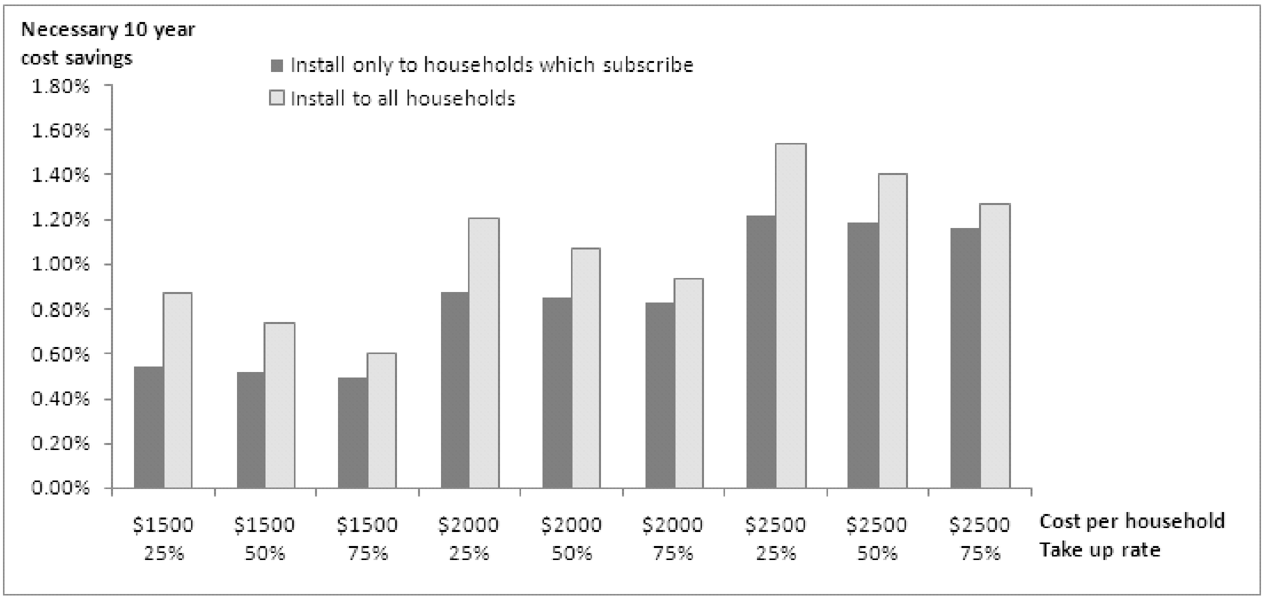
- Benefits in other, non-measured sectors: The benefits which would need to accrue from the incremental impact of a new broadband network are considered to be spread evenly across the four key sectors (electricity, health, transportation and education). There will be other costs associated with integrating new broadband applications into these sectors (*e.g.* purchasing new computer systems) but these investments can often be built into the planned capital expenditures of firms in each sector. Our very conservative estimates assume that the introduction of the new network decreases costs by a certain percentage across the lifetime of the investment. In reality the availability of a fibre broadband network to all households will likely continue providing efficiency gains as new secondary services appear to complement other primary fibre-based services. These additional gains are not considered.

Results

Overall, cost savings in each of the sectors would need to be between 0.5% and 1.5% to justify building a national fibre-to-the-home network. The lower range is tied to lower-cost rollouts (USD 1 500 per household) and the upper range for countries where rollout costs would be closer to USD 2 500 per household (see Figure 11). There are significant differences across countries, largely influenced by the size of the combined four sectors. The results on a country-by-country basis are presented in the Annex 2 and the cost model is detailed in Annex 3.

Costs are lower if the network operator builds networks down all streets but only connects homes which subscribe to Internet services. At the same time though, the highest efficiency gains will be tied to having all homes connected via dark fibre. For example, smart grid operators or health providers may need connectivity to all households, not just broadband subscribers, in order for smart electricity applications to work efficiently. In the model, installing lines to all households, not just subscribers, increases the costs by an average of 22% (assuming a 50% take-up rate). The cost difference decreases as penetration rises.

Figure 10. Necessary cost savings across 4 key sectors over 10 years to justify an FTTH rollout



It can also be informative to examine individual sectors to see what types of impacts are plausible and whether a 0.5% to 1.5% reduction in costs over 10 years is feasible. Siddiqui (2008) examines the potential impact of smart grid infrastructure in the United States and concludes that new technologies could reduce residential energy consumption by 5% in the residential sector and 2.5% in the industrial and commercial sector. To put the size of the potential savings in perspective, a savings of 4% to 11% over 10 years in the electricity sector alone is large enough, on average, to pay to build a national fibre-to-the-home network without taking into account any other spillover effects.

Health is one of the largest spending categories in the OECD and achieving a 0.5% to 1.5% reduction in costs attributed to broadband is equivalent to reducing total monthly expenditures of USD 884 by USD 5 – USD 14 per month over 10 years. Savings in the health sector alone could justify the cost of rolling out a network if health costs were to fall between 1.4% and 3.7% as a direct result of having the network in place.

Finally, the introduction of intelligent transportation systems and telecommuting over the new fibre network could largely help justify the cost of rolling out a new fibre-to-the-home network. A 0.5% to 1.5% reduction in all household transportation expenditures is equivalent to a saving of between USD 3 – USD 7 per month for each household out of a total of USD 432 of monthly spending. Funding the entire network using transportation savings would only require a USD 12 to USD 33 saving per month for each household, less than the typical cost of one monthly public transportation pass.

Changing the parameters of the analysis will have an effect on the amount of savings to reimburse network buildout costs but even the most expensive rollouts still only require a relatively small percentage reduction in sector costs to be considered worthwhile. In cases where broadband networks can be installed for USD 1 500 per household or less the cost savings which are directly tied to the new broadband network typically need not be larger than 1% of total expenditures in the four sectors.

ANNEX 1: NET FTTH BUILDOUT COSTS AND SECTORAL SPENDING

Low-cost rollout (USD 1 500) / Low take-up (25%) / Connecting all homes

Interest rate	5.00%
Amortisation (years)	10
Take-up rate (%)	25%
Price of unbundled line (USD)	$14.00
OPEX cost per household per month (USD)	$3.00
Total FTTH installation cost per household (USD)	$1 500.00
FTTH installation (price to pass household with network, USD)	$ 850.00
FTTH installation (price to connect household from street, USD)	$ 650.00

	FTTH rollout as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	3.50%	3.90%	3.96%	2.43%	0.83%
Austria	4.86%	4.38%	4.05%	1.96%	0.84%
Belgium	5.13%	4.12%	4.68%	2.01%	0.87%
Canada	2.41%	3.79%	4.15%	1.73%	0.67%
Czech Republic	6.64%	14.76%	12.32%	7.25%	2.29%
Denmark	3.76%	2.82%	4.83%	1.77%	0.72%
Finland	3.31%	4.36%	4.51%	2.54%	0.87%
France	6.48%	4.15%	3.04%	1.89%	0.80%
Germany	7.11%	5.86%	5.30%	2.42%	1.10%
Greece	6.50%	7.47%	5.26%	2.59%	1.16%
Hungary	8.38%	13.56%	9.47%	8.18%	2.38%
Iceland	1.32%	1.94%	2.80%	1.35%	0.42%
Ireland	3.75%	2.82%	3.21%	1.32%	0.59%
Italy	5.27%	5.77%	4.08%	2.32%	0.96%
Japan	4.82%	4.51%		2.87%	..
Korea (Rep. of)	8.77%	5.79%	7.77%	5.40%	1.67%
Luxembourg	2.24%		1.83%	1.30%	..
Mexico	24.22%	9.94%		9.15%	..
Netherlands	5.46%	4.72%	5.11%	2.00%	0.92%
New Zealand	4.49%	4.42%		2.70%	..
Norway	2.20%	2.53%	3.60%	1.14%	0.50%
Poland	12.07%	16.43%	18.25%	10.84%	3.44%
Portugal	6.44%	7.16%	6.70%	3.96%	1.43%
Slovak Republic	9.26%	24.26%	21.10%	8.86%	3.23%
Spain	6.28%	6.11%	4.80%	2.64%	1.10%
Sweden	3.39%	4.00%	4.66%	2.27%	0.83%
Switzerland	7.23%	3.11%		1.53%	..
Turkey	13.98%			12.11%	..
United Kingdom	6.29%	3.76%	3.04%	2.27%	0.84%
United States	5.95%	2.81%	3.44%	1.13%	0.59%
OECD	5.99%	4.19%	4.11%	2.00%	0.87%

Low-cost rollout (USD 1 500) / Med take-up (50%) / Connecting all homes

Interest rate	5.00%
Amortisation (years)	10
Take-up rate (%)	50%
Price of unbundled line (USD)	$14.00
OPEX cost per household per month (USD)	$3.00
Total FTTH installation cost per household (USD)	$1 500.00
FTTH installation (price to pass household with network, USD)	$ 850.00
FTTH installation (price to connect household from street, USD)	$ 650.00

	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	2.96%	3.29%	3.34%	2.05%	0.70%
Austria	4.11%	3.70%	3.43%	1.66%	0.71%
Belgium	4.33%	3.48%	3.96%	1.70%	0.74%
Canada	2.04%	3.20%	3.51%	1.46%	0.56%
Czech Republic	5.61%	12.47%	10.41%	6.13%	1.93%
Denmark	3.18%	2.38%	4.08%	1.49%	0.61%
Finland	2.79%	3.68%	3.81%	2.15%	0.74%
France	5.48%	3.51%	2.57%	1.59%	0.67%
Germany	6.00%	4.95%	4.48%	2.05%	0.93%
Greece	5.50%	6.31%	4.45%	2.19%	0.98%
Hungary	7.08%	11.45%	8.00%	6.91%	2.01%
Iceland	1.12%	1.64%	2.36%	1.14%	0.36%
Ireland	3.17%	2.38%	2.72%	1.12%	0.50%
Italy	4.45%	4.88%	3.45%	1.96%	0.81%
Japan	4.07%	3.81%		2.42%	..
Korea (Rep. of)	7.41%	4.89%	6.57%	4.56%	1.41%
Luxembourg	1.89%		1.55%	1.10%	..
Mexico	20.46%	8.40%		7.73%	..
Netherlands	4.61%	3.98%	4.32%	1.69%	0.77%
New Zealand	3.79%	3.74%		2.28%	..
Norway	1.86%	2.14%	3.04%	0.96%	0.42%
Poland	10.20%	13.88%	15.42%	9.15%	2.91%
Portugal	5.44%	6.05%	5.66%	3.34%	1.21%
Slovak Republic	7.82%	20.50%	17.83%	7.49%	2.73%
Spain	5.30%	5.16%	4.06%	2.23%	0.93%
Sweden	2.86%	3.38%	3.94%	1.92%	0.70%
Switzerland	6.11%	2.63%		1.29%	..
Turkey	11.81%			10.23%	..
United Kingdom	5.31%	3.18%	2.57%	1.92%	0.71%
United States	5.03%	2.37%	2.91%	0.95%	0.50%
OECD	5.06%	3.54%	3.47%	1.69%	0.74%

Low-cost rollout (USD 1 500) / High take-up (75%) / Connecting all homes					
Interest rate					5.00%
Amortisation (years)					10
Take-up rate (%)					75%
Price of unbundled line (USD)					$14.00
OPEX cost per household per month (USD)					$3.00
Total FTTH installation cost per household (USD)					$1 500.00
FTTH installation (price to pass household with network, USD)					$ 850.00
FTTH installation (price to connect household from street, USD)					$ 650.00
	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	2.41%	2.69%	2.73%	1.68%	0.57%
Austria	3.35%	3.02%	2.80%	1.35%	0.58%
Belgium	3.54%	2.84%	3.23%	1.39%	0.60%
Canada	1.67%	2.61%	2.87%	1.19%	0.46%
Czech Republic	4.58%	10.18%	8.50%	5.00%	1.58%
Denmark	2.59%	1.94%	3.33%	1.22%	0.50%
Finland	2.28%	3.01%	3.11%	1.75%	0.60%
France	4.47%	2.86%	2.10%	1.30%	0.55%
Germany	4.90%	4.04%	3.65%	1.67%	0.76%
Greece	4.49%	5.15%	3.63%	1.78%	0.80%
Hungary	5.78%	9.35%	6.53%	5.64%	1.64%
Iceland	0.91%	1.34%	1.93%	0.93%	0.29%
Ireland	2.59%	1.94%	2.22%	0.91%	0.41%
Italy	3.64%	3.98%	2.81%	1.60%	0.66%
Japan	3.33%	3.11%		1.98%	..
Korea (Rep. of)	6.05%	3.99%	5.36%	3.73%	1.15%
Luxembourg	1.54%		1.26%	0.90%	..
Mexico	16.71%	6.86%		6.31%	..
Netherlands	3.76%	3.25%	3.52%	1.38%	0.63%
New Zealand	3.10%	3.05%		1.86%	..
Norway	1.52%	1.75%	2.48%	0.78%	0.34%
Poland	8.33%	11.33%	12.59%	7.47%	2.37%
Portugal	4.44%	4.94%	4.62%	2.73%	0.99%
Slovak Republic	6.39%	16.74%	14.55%	6.11%	2.23%
Spain	4.33%	4.21%	3.31%	1.82%	0.76%
Sweden	2.34%	2.76%	3.22%	1.57%	0.58%
Switzerland	4.99%	2.14%		1.05%	..
Turkey	9.64%			8.35%	..
United Kingdom	4.34%	2.59%	2.10%	1.57%	0.58%
United States	4.11%	1.94%	2.38%	0.78%	0.41%
OECD	4.13%	2.89%	2.83%	1.38%	0.60%

Med-cost rollout (USD 2 000) / Low take-up (25%) / Connecting all homes					
Interest rate					5.00%
Amortisation (years)					10
Take-up rate (%)					25%
Price of unbundled line (USD)					$14.00
OPEX cost per household per month (USD)					$3.00
Total FTTH installation cost per household (USD)					$2 000.00
FTTH installation (price to pass household with network, USD)					$1 350.00
FTTH installation (price to connect household from street, USD)					$ 650.00
	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	4.85%	5.40%	5.48%	3.37%	1.15%
Austria	6.74%	6.06%	5.62%	2.71%	1.16%
Belgium	7.10%	5.70%	6.49%	2.79%	1.21%
Canada	3.34%	5.25%	5.75%	2.39%	0.92%
Czech Republic	9.20%	20.44%	17.06%	10.05%	3.17%
Denmark	5.21%	3.90%	6.70%	2.45%	0.99%
Finland	4.58%	6.04%	6.25%	3.52%	1.21%
France	8.98%	5.75%	4.22%	2.61%	1.10%
Germany	9.84%	8.12%	7.34%	3.35%	1.52%
Greece	9.01%	10.34%	7.29%	3.58%	1.60%
Hungary	11.61%	18.78%	13.12%	11.33%	3.29%
Iceland	1.83%	2.68%	3.87%	1.87%	0.58%
Ireland	5.19%	3.91%	4.45%	1.83%	0.82%
Italy	7.30%	7.99%	5.65%	3.21%	1.33%
Japan	6.68%	6.24%		3.97%	..
Korea (Rep. of)	12.15%	8.02%	10.76%	7.48%	2.31%
Luxembourg	3.10%		2.54%	1.80%	..
Mexico	33.55%	13.77%		12.68%	..
Netherlands	7.56%	6.53%	7.08%	2.77%	1.27%
New Zealand	6.22%	6.12%		3.74%	..
Norway	3.05%	3.51%	4.98%	1.57%	0.69%
Poland	16.72%	22.75%	25.28%	15.01%	4.76%
Portugal	8.92%	9.92%	9.28%	5.48%	1.99%
Slovak Republic	12.82%	33.60%	29.22%	12.28%	4.48%
Spain	8.69%	8.46%	6.65%	3.66%	1.52%
Sweden	4.69%	5.54%	6.46%	3.15%	1.15%
Switzerland	10.01%	4.31%		2.11%	..
Turkey	19.36%			16.77%	..
United Kingdom	8.71%	5.21%	4.21%	3.14%	1.16%
United States	8.24%	3.89%	4.77%	1.56%	0.81%
OECD	8.29%	5.80%	5.69%	2.78%	1.21%

Med-cost rollout (USD 2 000) / Med take-up (50%) / Connecting all homes					
Interest rate					5.00%
Amortisation (years)					10
Take-up rate (%)					50%
Price of unbundled line (USD)					$14.00
OPEX cost per household per month (USD)					$3.00
Total FTTH installation cost per household (USD)					$2 000.00
FTTH installation (price to pass household with network, USD)					$1 350.00
FTTH installation (price to connect household from street, USD)					$ 650.00
	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	4.31%	4.79%	4.87%	2.99%	1.02%
Austria	5.98%	5.38%	4.99%	2.41%	1.03%
Belgium	6.31%	5.07%	5.76%	2.47%	1.07%
Canada	2.97%	4.66%	5.11%	2.12%	0.82%
Czech Republic	8.17%	18.15%	15.15%	8.92%	2.81%
Denmark	4.63%	3.46%	5.95%	2.17%	0.88%
Finland	4.07%	5.36%	5.55%	3.12%	1.07%
France	7.97%	5.10%	3.74%	2.32%	0.98%
Germany	8.74%	7.21%	6.51%	2.98%	1.35%
Greece	8.00%	9.18%	6.47%	3.18%	1.42%
Hungary	10.31%	16.67%	11.65%	10.06%	2.92%
Iceland	1.62%	2.38%	3.44%	1.66%	0.52%
Ireland	4.61%	3.47%	3.95%	1.63%	0.73%
Italy	6.48%	7.10%	5.02%	2.85%	1.18%
Japan	5.93%	5.55%		3.53%	..
Korea (Rep. of)	10.79%	7.12%	9.56%	6.64%	2.05%
Luxembourg	2.75%		2.25%	1.60%	..
Mexico	29.79%	12.23%		11.26%	..
Netherlands	6.71%	5.80%	6.28%	2.46%	1.13%
New Zealand	5.52%	5.44%		3.32%	..
Norway	2.71%	3.12%	4.42%	1.40%	0.61%
Poland	14.85%	20.21%	22.45%	13.33%	4.23%
Portugal	7.92%	8.81%	8.25%	4.87%	1.76%
Slovak Republic	11.39%	29.84%	25.95%	10.90%	3.97%
Spain	7.72%	7.51%	5.91%	3.25%	1.35%
Sweden	4.17%	4.92%	5.73%	2.80%	1.03%
Switzerland	8.89%	3.82%		1.88%	..
Turkey	17.19%			14.89%	..
United Kingdom	7.73%	4.62%	3.74%	2.79%	1.03%
United States	7.32%	3.45%	4.24%	1.39%	0.72%
OECD	7.36%	5.15%	5.05%	2.47%	1.07%

Med-cost rollout (USD 2 000) / High take-up (75%) / Connecting all homes					
Interest rate					5.00%
Amortisation (years)					10
Take-up rate (%)					75%
Price of unbundled line (USD)					$14.00
OPEX cost per household per month (USD)					$3.00
Total FTTH installation cost per household (USD)					$2 000.00
FTTH installation (price to pass household with network, USD)					$1 350.00
FTTH installation (price to connect household from street, USD)					$ 650.00
	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	3.76%	4.19%	4.25%	2.61%	0.89%
Austria	5.23%	4.70%	4.36%	2.11%	0.90%
Belgium	5.51%	4.43%	5.03%	2.16%	0.94%
Canada	2.59%	4.07%	4.47%	1.86%	0.72%
Czech Republic	7.14%	15.86%	13.24%	7.80%	2.46%
Denmark	4.04%	3.03%	5.20%	1.90%	0.77%
Finland	3.55%	4.68%	4.85%	2.73%	0.94%
France	6.97%	4.46%	3.27%	2.03%	0.86%
Germany	7.64%	6.30%	5.69%	2.60%	1.18%
Greece	6.99%	8.03%	5.66%	2.78%	1.24%
Hungary	9.01%	14.57%	10.18%	8.80%	2.55%
Iceland	1.42%	2.08%	3.00%	1.45%	0.45%
Ireland	4.03%	3.03%	3.45%	1.42%	0.64%
Italy	5.66%	6.20%	4.39%	2.49%	1.03%
Japan	5.18%	4.85%		3.08%	..
Korea (Rep. of)	9.43%	6.22%	8.35%	5.80%	1.79%
Luxembourg	2.40%		1.97%	1.40%	..
Mexico	26.03%	10.69%		9.84%	..
Netherlands	5.86%	5.07%	5.49%	2.15%	0.99%
New Zealand	4.83%	4.75%		2.91%	..
Norway	2.37%	2.72%	3.86%	1.22%	0.54%
Poland	12.97%	17.66%	19.62%	11.65%	3.70%
Portugal	6.92%	7.70%	7.21%	4.25%	1.54%
Slovak Republic	9.95%	26.08%	22.68%	9.53%	3.47%
Spain	6.75%	6.56%	5.16%	2.84%	1.18%
Sweden	3.64%	4.30%	5.01%	2.44%	0.90%
Switzerland	7.77%	3.34%		1.64%	..
Turkey	15.03%			13.01%	..
United Kingdom	6.76%	4.04%	3.27%	2.44%	0.90%
United States	6.40%	3.02%	3.70%	1.21%	0.63%
OECD	6.43%	4.50%	4.41%	2.15%	0.94%

High-cost rollout (USD 2 500) / Low take-up (25%) / Connecting all homes

Interest rate	5.00%
Amortisation (years)	10
Take-up rate (%)	25%
Price of unbundled line (USD)	$14.00
OPEX cost per household per month (USD)	$3.00
Total FTTH installation cost per household (USD)	$2 500.00
FTTH installation (price to pass household with network, USD)	$1 850.00
FTTH installation (price to connect household from street, USD)	$ 650.00

	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	6.20%	6.90%	7.00%	4.30%	1.47%
Austria	8.61%	7.74%	7.18%	3.47%	1.49%
Belgium	9.08%	7.29%	8.29%	3.56%	1.54%
Canada	4.27%	6.71%	7.35%	3.06%	1.18%
Czech Republic	11.76%	26.12%	21.80%	12.84%	4.05%
Denmark	6.66%	4.99%	8.56%	3.13%	1.27%
Finland	5.85%	7.71%	7.98%	4.50%	1.54%
France	11.47%	7.34%	5.39%	3.34%	1.41%
Germany	12.58%	10.37%	9.38%	4.28%	1.94%
Greece	11.51%	13.22%	9.31%	4.58%	2.05%
Hungary	14.83%	24.00%	16.76%	14.48%	4.21%
Iceland	2.34%	3.43%	4.95%	2.39%	0.75%
Ireland	6.63%	4.99%	5.69%	2.34%	1.05%
Italy	9.33%	10.22%	7.22%	4.11%	1.70%
Japan	8.54%	7.98%		5.07%	..
Korea (Rep. of)	15.53%	10.25%	13.75%	9.56%	2.95%
Luxembourg	3.96%		3.24%	2.30%	..
Mexico	42.87%	17.60%		16.20%	..
Netherlands	9.66%	8.35%	9.04%	3.54%	1.62%
New Zealand	7.95%	7.83%		4.78%	..
Norway	3.90%	4.49%	6.36%	2.01%	0.88%
Poland	21.36%	29.08%	32.30%	19.18%	6.09%
Portugal	11.40%	12.67%	11.87%	7.00%	2.54%
Slovak Republic	16.39%	42.94%	37.35%	15.69%	5.72%
Spain	11.11%	10.81%	8.50%	4.67%	1.95%
Sweden	6.00%	7.09%	8.25%	4.03%	1.48%
Switzerland	12.80%	5.50%		2.70%	..
Turkey	24.75%			21.43%	..
United Kingdom	11.13%	6.66%	5.38%	4.02%	1.48%
United States	10.53%	4.97%	6.10%	1.99%	1.04%
OECD	10.59%	7.42%	7.27%	3.55%	1.54%

High-cost rollout (USD 2 500) / Med take-up (50%) / Connecting all homes					
Interest rate					5.00%
Amortisation (years)					10
Take-up rate (%)					50%
Price of unbundled line (USD)					$14.00
OPEX cost per household per month (USD)					$3.00
Total FTTH installation cost per household (USD)					$2 500.00
FTTH installation (price to pass household with network, USD)					$1 850.00
FTTH installation (price to connect household from street, USD)					$ 650.00
	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	5.65%	6.30%	6.39%	3.93%	1.34%
Austria	7.85%	7.07%	6.55%	3.16%	1.36%
Belgium	8.28%	6.65%	7.56%	3.25%	1.41%
Canada	3.90%	6.12%	6.71%	2.79%	1.08%
Czech Republic	10.73%	23.83%	19.89%	11.71%	3.69%
Denmark	6.07%	4.55%	7.81%	2.85%	1.16%
Finland	5.34%	7.04%	7.28%	4.10%	1.41%
France	10.47%	6.70%	4.92%	3.05%	1.29%
Germany	11.48%	9.47%	8.55%	3.91%	1.77%
Greece	10.50%	12.06%	8.50%	4.18%	1.87%
Hungary	13.54%	21.89%	15.29%	13.21%	3.84%
Iceland	2.13%	3.13%	4.51%	2.18%	0.68%
Ireland	6.05%	4.55%	5.19%	2.14%	0.96%
Italy	8.51%	9.32%	6.59%	3.75%	1.55%
Japan	7.79%	7.28%		4.63%	..
Korea (Rep. of)	14.17%	9.35%	12.55%	8.72%	2.69%
Luxembourg	3.61%		2.96%	2.10%	..
Mexico	39.12%	16.06%		14.78%	..
Netherlands	8.81%	7.62%	8.25%	3.23%	1.48%
New Zealand	7.25%	7.14%		4.37%	..
Norway	3.56%	4.09%	5.81%	1.83%	0.80%
Poland	19.49%	26.53%	29.47%	17.50%	5.55%
Portugal	10.40%	11.56%	10.83%	6.39%	2.32%
Slovak Republic	14.95%	39.18%	34.07%	14.31%	5.22%
Spain	10.14%	9.86%	7.76%	4.26%	1.77%
Sweden	5.47%	6.47%	7.53%	3.67%	1.35%
Switzerland	11.68%	5.02%		2.47%	..
Turkey	22.58%			19.55%	..
United Kingdom	10.15%	6.07%	4.91%	3.66%	1.35%
United States	9.61%	4.54%	5.56%	1.82%	0.95%
OECD	9.67%	6.77%	6.63%	3.24%	1.41%

High-cost rollout (USD 2 500) / High take-up (75%) / Connecting all homes

Interest rate	5.00%
Amortisation (years)	10
Take-up rate (%)	75%
Price of unbundled line (USD)	$14.00
OPEX cost per household per month (USD)	$3.00
Total FTTH installation cost per household (USD)	$2 500.00
FTTH installation (price to pass household with network, USD)	$1 850.00
FTTH installation (price to connect household from street, USD)	$ 650.00

	FTTH rollout costs as % of electricity spending	FTTH rollout costs as % of education spending	FTTH rollout costs as % of transport spending	FTTH rollout costs as % of health spending	FTTH rollout costs as % of total spending (4 sectors)
Australia	5.11%	5.69%	5.78%	3.55%	1.21%
Austria	7.10%	6.39%	5.92%	2.86%	1.23%
Belgium	7.49%	6.01%	6.84%	2.94%	1.27%
Canada	3.52%	5.53%	6.06%	2.52%	0.97%
Czech Republic	9.70%	21.54%	17.98%	10.59%	3.34%
Denmark	5.49%	4.11%	7.06%	2.58%	1.05%
Finland	4.83%	6.36%	6.59%	3.71%	1.27%
France	9.46%	6.06%	4.44%	2.75%	1.16%
Germany	10.37%	8.56%	7.73%	3.53%	1.60%
Greece	9.50%	10.90%	7.68%	3.78%	1.69%
Hungary	12.24%	19.79%	13.83%	11.95%	3.47%
Iceland	1.93%	2.83%	4.08%	1.97%	0.62%
Ireland	5.47%	4.12%	4.69%	1.93%	0.86%
Italy	7.69%	8.43%	5.96%	3.39%	1.41%
Japan	7.04%	6.58%		4.19%	..
Korea (Rep. of)	12.81%	8.45%	11.34%	7.88%	2.43%
Luxembourg	3.27%		2.67%	1.90%	..
Mexico	35.36%	14.52%		13.36%	..
Netherlands	7.96%	6.89%	7.46%	2.92%	1.34%
New Zealand	6.56%	6.45%		3.95%	..
Norway	3.22%	3.70%	5.25%	1.66%	0.73%
Poland	17.62%	23.98%	26.64%	15.82%	5.02%
Portugal	9.40%	10.45%	9.79%	5.77%	2.09%
Slovak Republic	13.52%	35.42%	30.80%	12.94%	4.72%
Spain	9.16%	8.91%	7.01%	3.86%	1.60%
Sweden	4.95%	5.84%	6.81%	3.32%	1.22%
Switzerland	10.55%	4.54%		2.23%	..
Turkey	20.41%			17.67%	..
United Kingdom	9.18%	5.49%	4.44%	3.31%	1.22%
United States	8.69%	4.10%	5.03%	1.64%	0.86%
OECD	8.74%	6.12%	5.99%	2.93%	1.27%

ANNEX 2: SPILLOVERS IN OTHER SECTORS

Additional spillovers

The analysis in the paper focuses on four key sectors of the economy that have data on expenditures. There are, however, other key innovative areas of the economy which rely heavily on broadband networks. This annex examines three of these areas in more detail: grid computing, cloud computing and content distribution.

Grid computing

Upgraded broadband networks enable grid computing – the efficient pooling of computing capacity to solve many of the research questions which have been too large for individual super-computers to efficiently calculate. Grid computing was initially designed for advanced science and engineering projects but is now used for a wide range of applications (OECD 2002). Broadband networks will play an increasingly important role as the processing power of individual computers increases – allowing them to receive ever larger amounts of data, process it, and return the results more quickly.

The collective latent computing capabilities of the world's estimated 1 billion computers is almost incomprehensible. Unfortunately, proponents of nefarious applications for harnessing this resource have so far been very much ahead of the innovation curve. One striking example is the botnet created by a worm known as "Storm," which is estimated to have infected between 1 million – 50 million computers worldwide, though precise estimates are difficult given the highly distributed and partitioned nature of the network.[46]

One very interesting calculation from August 2007 concluded that, assuming that the average infected machine had a 2.3 - 3.3 GHz single core CPU with around 1GB of RAM, the Storm computing cluster would have the equivalent of between one and ten million 2.8 GHz Pentium 4 processors with 1 - 10 petabytes of RAM. Not only would this make the Storm cluster vastly more powerful than the largest supercomputer on the planet, IBM's BlueGene, but would also give it more computing resources than the top ten supercomputers in the world.[47]

To date, Storm has yet to produce the cataclysmic attacks envisaged in 2007, and while the world still awaits a definitive answer as to what Storm's authors have in mind, the "pioneering" work of such botnet authors nevertheless highlights the tremendous potential of distributed computing applications which harness the latent processing capacity of hundreds of millions of networked computers worldwide. Sadly, benevolent uses of latent computing cycles via the public Internet lag considerably in penetration rates, due to their voluntary participatory nature. Nevertheless, there are a number of interesting examples in existence which demonstrate the power of distributed computing resources.

Perhaps the best known example in the mainstream media is the Search for Extraterrestrial Intelligence (more commonly known as SETI@home) project from the University of California at Berkeley. Now in its tenth year, the SETI project uses latent computing power on idle PCs to analyse data collected by radio telescopes, in the hope of identifying signifiers of extraterrestrial intelligence. This is achieved by encouraging participants to download and run a version of the Berkeley Open Infrastructure for Network Computing client application (a.k.a. BOINC, which powers a large number of other similar projects), which allocates a portion of the project data processing task to individual client computers during periods in which they are determined to be idle.

At present, the SETI project, with 2.26 million computers in production, accounts for 56% of the total 4.03 million active BOINC installations worldwide (representing a total of 1.65 million project members).[48] Other noteworthy BOINC-based distributed computing projects include:

- **Einstein@Home**, which searches for pulsars and radio pulsars using data from the LIGO gravitational wave detector and the Arecibo Observatory, with 864 000 active computers in production.

- **Rosetta (a.k.a. Rosetta@home)**, a protein analysis research project targeting possible treatments for HIV, malaria, Alzheimer's disease and cancer, which currently numbers 714 000 active computers in production.

- **World Community Grid**, an IBM-sponsored project which comprises a number of research programs addressing disease prevention/cure, sustainable agriculture, clean energy and genetics, with a total of 654 000 active computers in production.

- **Climateprediction.net**, a project which strives to predict climate change to the year 2080, by running vast numbers of variations of model assumptions within the seven core experiments in the project. Climateprediction.net currently has 363 000 active computers in production.

Technically speaking, these BOINC-based projects do not require broadband connections to function, as evidenced by the fact that BOINC was first developed and deployed in 1999, before broadband as a mainstream consumer proposition even existed. Ultimately, the BOINC distributed computing projects rely on acquiring a large number of participants and incentivising them to contribute as much computing resource as possible on a recurring basis. This is typically achieved by creating a competitive ranking system of project members, using credits for data analysis batches completed, or data volumes contributed. Broadband, however, allows much larger data batches to be distributed to project members, and their results to be reported back to the study, in a much more efficient manner, allowing the project to progress more rapidly than it would otherwise.

While many of the larger distributed computing projects function by successfully aggregating computing capacity across an interest group which may be global in scope, there is evidence within smaller projects of a highly localised interest group with explicit ties to broadband infrastructure policy. One such example is the AlmereGrid in the Netherlands. Almere is a late 1970s “new town,” with a population of roughly 185 000, and is estimated to be the fastest growing city in Europe. In 2003, the city began construction of a FTTH pilot project, with the goal of creating a three-layer open network, in which the municipality owns the underlying passive infrastructure and awards network management to a neutral party, which in turn opens the network to service providers on a non-discriminatory commercial basis.[49]

In 2004, the AlmereGrid project was launched, with the explicit goal of employing the computing resources of users connected to the FTTH network.[50] Initially, AlmereGrid focused its resources on academic research, notably a project to analyse bone density scans (with large file sizes) compiled by the Erasmus Medical Center in Rotterdam.[51] The project now claims 2 500 computers in active production, and the utility of the grid has been expanded to include shared encrypted data backup for local SMEs, as well as a project (Digitale Wooncoach) to allow future residents of a planned housing development to visualize and customise design elements and interact with other entities and agencies involved in the project.

Cloud computing

While grid computing disaggregates computing tasks over hundreds of thousands of computers, *cloud computing* represents an important innovation by efficiently centralising computing power and resources across the Internet. This allows small and medium-sized businesses to employ scalable computing resources from a third party commercial provider subject to the actual demand for their services in the market. Broadband networks are the vital communication channel between users, small and medium-sized businesses and the cloud computing provider.

The upgrade of broadband networks also plays an indirect role by facilitating fast communication between businesses and consumers. Higher bandwidth between users and service providers means more potential demand for innovative new services from enterprises relying on cloud computing.

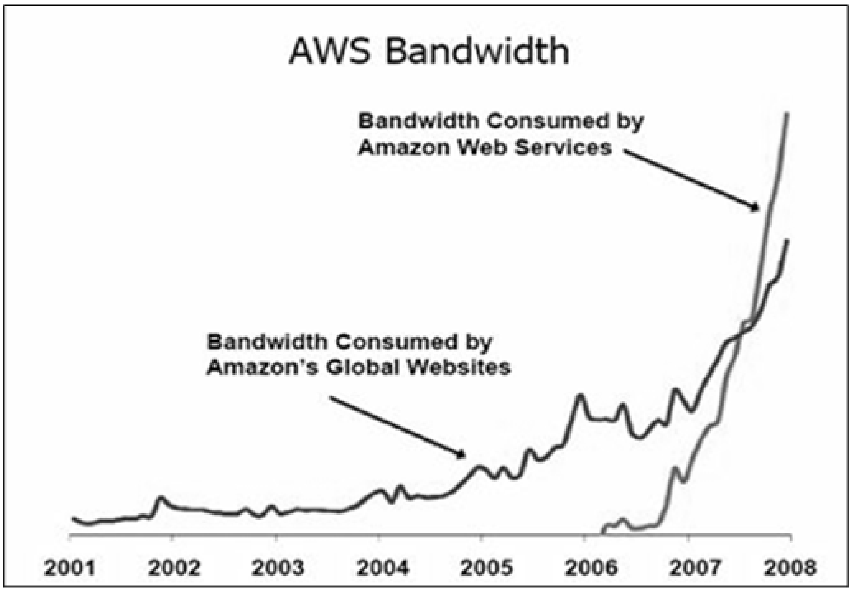
The terms "cloud computing," "virtualisation," and "web services" have become common in recent years, perhaps reflecting the fact that most Internet users, whether they realise it or not, are to some extent direct consumers of services and applications which live somewhere "in the cloud." The most common examples of these web services are probably webmail applications such as Hotmail and Google Mail, social networking sites such as Facebook and MySpace, large-scale commerce sites such as Amazon and eBay, and photo/video sharing sites such as Flickr and Picasa. The high levels of adoption of these services are testimony to the potential of cloud computing. While these applications appear (largely) painless to the end-user, they are underpinned by a very non-trivial level of technological sophistication, involving the large-scale manipulation of computing resources often controlled by parties otherwise uninvolved.

Whereas the examples of grid computing discussed in the previous section seek to aggregate and harness excess computing power across a defined universe of machines typically owned by parties opting in on the basis of contributing spare computing cycles during idle periods, cloud computing allows the user to employ elastic computing resources available from a third party commercial provider subject to demand, creating and destroying virtual computing instantiations as required, with a usage-base charging model.

The driving concept behind cloud computing is scalability, as many of its early adopters, such as application developers for Facebook or independent "viral" video sites, may see sudden and unpredictable spikes in the popularity of applications or content. In some cases, the surge in demand is such that the financial resources of a small company, or the physical or time limitations involved would ordinarily prohibit an adequate response, and the service would be overwhelmed by demand. Examples abound, but a "typical" case would be that of Animoto, a site built on virtual server and storage instances, which allows users to create their own videos using their personal photos and choice of soundtrack. Animoto launched on Facebook in April 2008, and within a matter three days, the computing resources required to satisfy user demand rose from 50 virtual server instances to 3 500[52] – a spike in demand which would have been physically and financially prohibitive for even large, well-resourced companies to respond to.

Animoto is just one of a large number of start-up companies making use of Amazon Web Services, commonly known as AWS. Though far from being alone, AWS is perhaps the best-known, and best-documented, provider of cloud computing services to date. AWS was created in 2002, but did not gain much visibility until March 2006, when it launched Simple Storage Service (S3), its cloud-based storage offering. This was followed in August 2006, by Elastic Compute Cloud (EC2), which offers virtual computing instantiations. These services initially ran within the spare capacity in Amazon's own core business infrastructure, but the rate of adoption by developers and start-up businesses was sufficiently rapid that Amazon had to create dedicated infrastructure. As shown in Figure 12, the amount of bandwidth consumed by AWS had already outstripped that consumed by Amazon's core business by mid-2008, and was projected to be roughly a third higher by year-end.[53] AWS has seen equally prodigious growth in storage, with its S3 storage service claiming 52 billion data objects at the end of March 2009, up from 18 billion a year earlier.[54]

Figure 11. Amazon Web Services bandwidth consumption trends



Source: Amazon.

Amazon's strategy in AWS development stems from a conscious decision to expose their core assets and capabilities to third parties, in an effort to broadly distribute the resources necessary to build a catalogue of products far larger than Amazon could ever do organically.[55] The introductions of S3 and EC2 formed the bedrock of a now-expanded suite of services, extending to Amazon's own store front, payment, fulfilment capabilities as well as database, map reduce, and its own Cloud Front content delivery network (Table 3). The availability of such resources on an as-needed, use-based charging basis gives start-up companies the flexibility to scale quickly, and fundamentally changes the economics of launching and maintaining a web-based business or application.

Table 3. Amazon Web Services EC2 pricing (Europe)

Standard On-Demand Instances	Linux/UNIX Usage	Windows Usage
Small (Default)	$0.11 per hour	$0.135 per hour
Large	$0.44 per hour	$0.54 per hour
Extra Large	$0.88 per hour	$1.08 per hour
High CPU On-Demand Instances	**Linux/UNIX Usage**	**Windows Usage**
Medium	$0.22 per hour	$0.32 per hour
Extra Large	$0.88 per hour	$1.28 per hour

Source: Amazon.

Other cloud computing services include software-as-a-service (SaaS) applications which allow users to work on documents, data and content on line through a standard web browser rather than through specialised software installed on a PC. These new services are gaining a significant following and may signal a shift to more network-based computing.

If this were to be the case broadband would become one of the most vital infrastructures for a wide range of computer applications. Any broadband limitations such as data caps or bandwidth constraints could hamper innovation in this growing sector.[56]

Content distribution

Digital delivery of information and products via the Internet and other computer-mediated networks is increasingly important for the distribution of information and commercial products and the ubiquity of digital content. It combines greater market reach with the capacity to engage in richer interaction with customers and consumers and has grown rapidly, aided by the widespread adoption of broadband technologies (OECD, 2004b).[57]

Broadband has become the leading delivery system for a wide range of content as witnessed by the transformation of the newspaper, music and video industries. Developments such as Amazon's e-book reader, Kindle, and initiatives by other libraries indicate that broadband may also become an important platform for the delivery of books. Video delivery, in particular, requires significant bandwidth to provide a high-quality television experience. Newly upgraded broadband networks in some countries are capable of delivering high-quality video-on-demand while the services in other countries are limited by bandwidth capacity either in access networks or on backhaul routes. Even with improvements in compression techniques, future content delivery will likely require very high data capacity to operate efficiently.

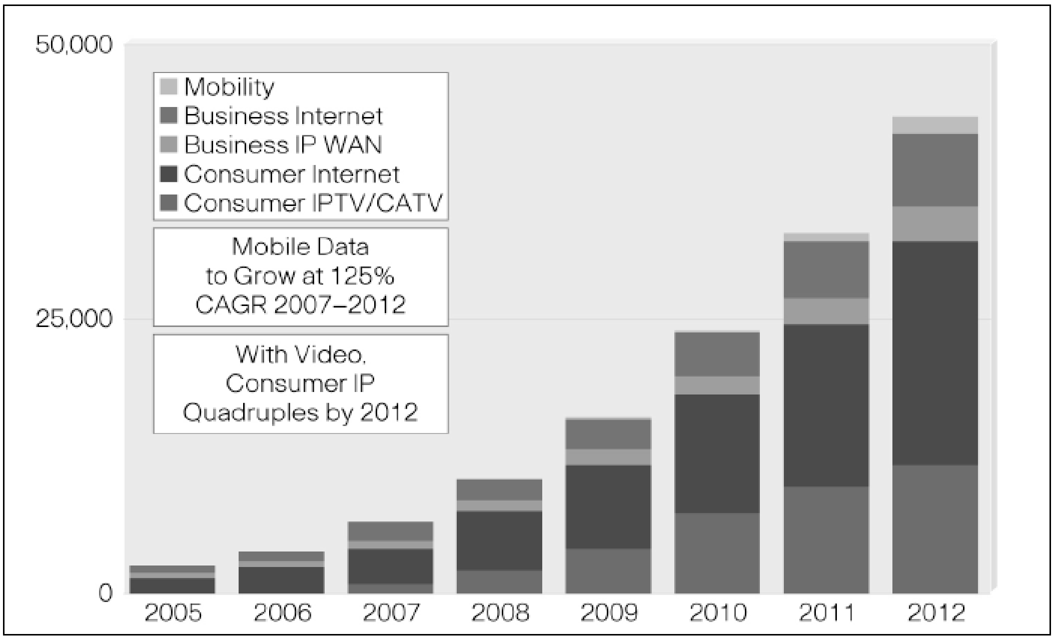
Much of the debate within industry in recent years surrounding incremental investment in network capacity management and provision has focused on the Internet as a platform for content distribution – primarily video. This debate has frequently been characterised as the "broadband incentive problem[58]," essentially involving a perceived mismatch between the demands placed on connectivity providers (primarily DSL and cable broadband players, but also a growing proportion of mobile operators) to provide ever-increasing levels of network capacity and performance so that customers may enjoy increasingly bandwidth-intensive applications, which, at best, generate only trivial incremental revenues for the connectivity provider. Stated more simply, broadband service providers have generally expressed a reticence to invest in next generation access network upgrades in the absence of a strong incremental revenue opportunity.

The source of anxiety for connectivity providers is well-illustrated in Cisco Systems' *Global IP Traffic Growth Forecast 2007 – 2012* report, published in June 2008. Among Cisco's projections are that global IP traffic in 2012, at 44 exabytes per month (equating roughly to 4 trillion high-definition feature-length films) will be a factor of six times the levels observed in 2007, and that the increase expected in the 2011 – 2012 calendar year will be larger than the cumulative growth during the 2000 – 2007 period.[59] Mobility contributes the highest growth rate during the forecast period but consumer Internet traffic accounts for the largest increment of growth, with nearly 90% of consumer Internet traffic accounted for by video-on-demand (VOD), IPTV and Internet video in 2012 (Figure 13).

It is widely assumed that the vast majority of the video-related traffic excluding telecommunication/cable IPTV/VOD will come from so-called "over the top" video services. The most prominent examples of these currently are YouTube, BBC iPlayer in the UK, NBC/NewsCorp's Hulu in the US market, and the SlingBox place-shifting device. Additionally, streamed gaming services such as G-Cluster in Japan, and the soon-to-launch OnLive deliver high performance versions of popular console and

PC game titles via the public Internet as a subscription service, and it may be expected that such over-the-top service strategies for gaming will expand in future.

Figure 12. Cisco global IP traffic growth forecast 2007 – 2012 (Petabytes per month)



Source: Cisco Visual Networking Index, June 2008.

The existence of these various over-the-top services is, in itself, very compelling evidence of the role of broadband in stimulating investment in innovative new technologies and business models. However, the opportunities created for these newcomers by broadband also impose costs on others in the value chain. The dilemma for broadband access providers is in how to balance the need to retain customers by giving them unfettered access to over-the-top video services with the significant incremental costs of delivering these more bandwidth-intensive applications, particularly given the ascendancy of high definition video. Various industry analyses have demonstrated that, at least in the UK market, the incremental bandwidth costs associated with over-the-top video services are sufficient to reduce the gross margins of small access providers.[60, 61] The access provider has a number of options for response, though none of them is particularly appealing:

- Investment in network capacity is one response, and anecdotally a commonly unavoidable one.
- Increasing prices to cover costs is possible in theory, but not always practical in highly competitive markets where broadband is sometimes a loss-leader for some other revenue stream.
- Blocking or throttling such content is technically possible, but highly controversial and likely to lead to customer dissatisfaction and churn.
- Pressuring content publishers to contribute to the costs of adding capacity to backhaul and transport networks is a commonly-cited tactic, and indeed in the UK this is an ongoing debate. However, with commercial broadcasters under mounting pressure from consumer behavioural changes and the downturn in advertising revenues, they are unlikely to comply. For a publicly-funded entity such as the BBC to divert revenues from viewer license fees toward telecom

infrastructure investment would be highly controversial. Moreover, many of the prominent players in the over-the-top video space are venture-backed companies lacking the financial sources for such an undertaking.

The prevalence of over-the-top services is thus both the product of innovation, as well as a driver of new innovation aimed at relieving the strain on networks of the services themselves, both in the interest of improving user experience and reducing costs for broadband access providers. These innovations fall into four broad categories:

- Codecs – Move Networks, a private US-based company which delivers over-the-top video content in HD-like quality on behalf of customers such as Fox, ABC and ESPN, addresses the issue of network congestion and latency by encoding publishers' content in multiple resolutions on its streaming servers, and then using the real-time feedback from its browser plug-in to assess the end user's network conditions and adjust the quality up or down in real-time, thus avoiding image buffering.[62]

- Edge and network caching – The explosive proliferation of video on the web has led to significant growth in the number of market participants hoping to capture the opportunities in the video content delivery network (CDN) arena.[63] The traditional CDN business model has been to serve content publishers with a solution which replicates content across the Internet in a distributed fashion to enhance user experience and prevent "flash mob" incidents which brought down major media websites in earlier stages of Internet development. However, for broadband access providers, the costs of video delivery to end customers can be dramatically reduced if as much of the associated traffic as possible can be kept within its own network. Content delivery network providers such as Akamai already strive to widely distribute cache servers as close to the end user as possible to ensure the best possible experience, but the next logical step is to push caches of content further into individual access providers' networks to increase the proportion of on-net traffic. One such example is the partnership between UK CDN company Velocix and Verizon Communications, wherein Velocix' Metro solution servers sit within Verizon's own network.[64] Arguably, such an arrangement can be a win-win for both the access provider, who may be able to negotiate some revenue share from the content owner, and for the content owner, who can ensure the best possible delivery of premium content with little associated capital investment.

- Peer-to-peer delivery systems – Peer-to-peer (P2P) has long been validated as an efficient and cost-effective solution for content distribution, albeit largely by communities of users engaged in unauthorised file sharing. The appeal of P2P is that, rather than having a centralised source of content (which can be costly in terms of bandwidth, hosting and server costs), P2P distributes the load across a large number of participating nodes, effectively distributing the cost of hosting and transit across thousands or millions of user accounts on hundreds of discreet access networks. A number of P2P protocols persist, and while official statistics on user numbers are elusive, it is widely accepted that the most popular is BitTorrent, initially created as a more economical way for Linux developers to distribute their software. Indeed, BitTorrent is still employed in this context, as a way to cheaply and efficiently distribute software updates and patches, perhaps most notably in the popular massively multiplayer online role-playing game (MMORPG) *World of Warcraft*. However, as with many technology innovations, early in its life BitTorrent saw mass adoption for a purpose other than that originally envisaged, and became the tool of choice for those seeking to move audio and video content across the Internet in a highly efficient, distributed fashion. Given the impressive performance of the BitTorrent protocol, and its high adoption rate, it is unsurprising that a number of start-up companies have appeared in the past five years with the intent of adapting BitTorrent or similar distributed computing concepts for use as a next generation CDN tool. While such P2P-enabled content delivery solutions are often popularly considered to be "long tail" technology, *i.e.,* well-suited to niche content due to the lower associated distribution costs, P2P actually functions more efficiently with a greater number of users, and thus the economics of P2P content distribution are in fact more suited to "fat tail" content, making it an ideal solution to deal with content which may experience overwhelming levels of demand. The best example of this to date is the choice by CNN to use a P2P solution from Octoshape for its streaming of the Obama inauguration, in which CNN.com alone served 25 million streams, making it the largest simultaneous online viewing experience in history. CNN's parent company, Turner Broadcasting, reportedly determined that conventional CDN architectures would not withstand the anticipated onslaught and decided that a P2P approach was the only viable solution.[65] In this case, the solution delivered was clearly shaped by the need to ensure quality on CNN's behalf, though in other implementations, P2P can be employed to prioritise on-net peers, so as to benefit the access provider.

- Hybrid content delivery networks – In an apparent recognition of the fact that the economics and technical considerations surrounding content delivery differ by publisher and specific piece of content, an increasing number of CDN providers are incorporating both conventional CDN architectures, as well as P2P solutions. Though adoption is still very low as a percentage of the total CDN market, the Octoshape/CNN experience shows that, in principal, the concept is sound. Where traditional CDN approaches function best, these will probably remain the *status quo* for the foreseeable future. Likewise, in situations where demand is likely to be unpredictable or extreme, the need to embrace P2P is probably unavoidable. As Internet video continues to grow, it is likely that solutions which dynamically incorporate both will become commonplace.

ANNEX 3: CALCULATION METHODOLOGY

Installation costs

Fibre-to-the-home installations are often broken down into two distinct costs. The first is to pass the home/premises with fibre in the street and the second is to run a line from the street to the home. The costs of passing and connecting are roughly equal.

Step 1: Passing the home

The costs for passing each home are given in Equation 1 and are simply the average cost of passing a household multiplied by the total number of households.

$$(1)\qquad \text{CostToPassAll} = (\text{average cost to pass each household}) \times (\text{total number of households})$$

Step 2: Connecting the home from the street

Once all premises are passed by the network there is a second installation that is needed to connect each home to the passing network. Operators have two choices. They can choose to connect all homes initially when they build the network, regardless of whether the household subscribes to services. The other choice is only to install this second leg once the household becomes a subscriber. Equation (2) calculates the cost of connecting of all homes, regardless of whether they subscribe and Equation (3) provides the cost to connect only subscribers

$$(2)\qquad \text{CostToConnectAll} = (\text{average cost to connect the line to each household}) \times (\text{total number of households})$$

$$(3)\qquad \text{CostToConnectSubsOnly} = (\text{average cost to connect the line to each household}) \times (\text{total number of } \textit{subscriber} \text{ households})$$

Financing calculations

The total buildout cost is determined by the costs to pass all homes, to connect all homes, financing charges. For this analysis we assume that all homes are connected, regardless of whether they subscribe or not. The total buildout cost is given in Equation (4).

$$(4)\qquad \text{TotalBuildoutCost} = (\text{CostToPassAll} + \text{CostToConnectAll}) \times \left(1 + \frac{\text{InterestRate}}{\text{CompoundsPerYear}}\right)^{(\text{NumberOfYears} \times \text{CompoundsPerYear})}$$

In the model we assign the following values: InterestRate = 5%, NumberOfYears = 10 and CompoundsPerYear = 2.

Consumer contributions

The model assumes that some of the monthly fees paid by subscribers are used to reimburse the capital costs of building the network. The consumer contribution is the amount of their subscription which pays for rental of the dark fibre line each month minus operational expenditures to operate and maintain the line. Only current subscribers contribute with their line rental. This contribution is given in Equation (5).

$$(5)\quad \text{CustomerContributionPayback} = (\text{UnbundlingFees} - \text{LineOPEX}) \times (\text{total number of } \textit{subscriber} \text{ households})$$

Therefore, the net cost of building the network is the total cost of building out the network minus the consumer's contribution to paying back capital costs, given in Equation (6).

$$(6)\quad \text{NetBuildoutCost} = \text{TotalBuildoutCost} - \text{CustomerContributionPayback}$$

Comparing net buildout costs with expenditures in other sectors

Once the net buildout costs have been computed they can be compared to expenditures in other sectors of the economy. The net buildout costs for the project are compared separately with expenditures on electricity, health, transportation, and education over the same time period.

Spending in each sector is first compared to the total costs of the network rollout (Equations 7, 8, 9, and 10). Then, all four sectors are combined to provide an estimate of how large an impact would be necessary across all four sectors at the same time to justify the investment in Equation (11).

$$(7)\quad \text{ElectricitySavingsNeeded} = \frac{\text{NetBuildoutCost}}{\text{TotalElectricityExpend}}$$

$$(8)\quad \text{HealthSavingsNeeded} = \frac{\text{NetBuildoutCost}}{\text{TotalHealthExpend}}$$

$$(9)\quad \text{TransportSavingsNeeded} = \frac{\text{NetBuildoutCost}}{\text{TotalTransportExpend}}$$

$$(10)\quad \text{EducationSavingsNeeded} = \frac{\text{NetBuildoutCost}}{\text{TotalEducationExpend}}$$

$$(11)\quad \text{TotalSavingsNeeded} = \frac{\text{NetFinancingCost}}{\text{TotalHealthExpend} + \text{TotalTransportExpend} + \text{TotalElectricityExpend} + \text{TotalEducationExpend}}$$

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