Study

The economic impact of Internet traffic growth on network operators

for submission to
Google

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Bad Honnef, 24 October 2014

Contents

Contents I

Figures III

Tables IV

1 Introduction 1

2 Connection and interconnection in the Internet 2

2.1 Peering, transit, and more exotic forms of interconnection among ISPs 2

2.2 How content providers invest to deliver their services 4

2.3 Conclusions 10

3 Understanding network costs and network prices 11

3.1 Costs and prices 13

3.2 Fixed costs versus usage-based costs 14

3.3 Moore's Law 17

3.4 Trends in relevant unit costs 19

3.4.1 Unit costs for equipment in the network core 19

3.4.2 Internet transit costs 21

3.4.3 Effects at the edge of fixed and mobile networks 24

3.5 Trends in traffic volumes 26

3.6 Trends in the number of subscribers 31

3.7 Trends in traffic per subscriber 34

3.8 Trends in pricing 38

3.9 Overall conclusions 44

4 Two-sided market theory and the Internet 46

4.1 Two-sided market theory 47

4.2 Two-sided markets and the Internet 49

4.3 The challenge of funding Next Generation Access (NGA) 52

4.3.1 The cost of fibre-based NGA poses a challenge to deployment 52

4.3.2 Challenges on the demand side 53

4.3.3 Cross subsidies between market sectors 56

4.4 Conclusions 56

5 Findings and conclusions **58**

5.1 Key findings 58

5.2 Recommendations to incumbent network operators 60

5.3 Recommendations to policymakers and regulators 61

References **62**

Figures

Figure 1:	Peering and transit relationships	4
Figure 2:	Monthly cost elements of a bundled DSL broadband/voice service (2013)	16
Figure 3:	Microprocessor Transistor Counts 1971-2011 & Moore's Law	18
Figure 4:	Price per Mbps (USD) and shipment quantities for high end routers	20
Figure 5:	Price per Mbps (USD) and shipment quantities for long haul DWDM	21
Figure 6:	Estimated IP transit prices in USD / Mbps (1998 - 2015)	22
Figure 7:	Global IP transit revenues (2013-2020)	23
Figure 8:	Advanced mobile technology significantly lowers unit costs	25
Figure 9:	Internet backbone traffic growth rates	27
Figure 10:	Cisco VNI forecast of global fixed Internet and managed IP traffic in Exabytes per month and associated growth rates (2014-2018)	28
Figure 11:	Global IP traffic by application category (2013-2018)	29
Figure 12:	Cisco VNI forecast of fixed plus mobile Internet traffic in Petabytes per month in Europe (2013-2018)	30
Figure 13:	Cisco VNI forecast of mobile Internet traffic in Exabytes per month and associated growth rates (2014-2018)	31
Figure 14:	Worldwide fixed broadband subscribers	32
Figure 15:	Fixed broadband subscriptions for OECD members	33
Figure 16:	Growth in the number of fixed subscribers in Europe (2003-2012)	34
Figure 17:	Number of subscribers and projected traffic in Exabytes (2013-2018)	36
Figure 18:	Projected traffic per fixed subscriber in Gigabytes per month and growth rate (2013 2018)	37
Figure 19:	Average Revenue per User (ARPU) in GBP for fixed broadband in selected countries (2007-2012)	39
Figure 20:	Prevalence of bit / data usage caps among surveyed offers (September 2012)	43
Figure 21:	Average data caps (GB), logarithmic scale (September 2012)	44
Figure 22:	A two sided market	48
Figure 23:	Subscription and usage fees in a two-sided market	49
Figure 24:	Application services, ISPs, and end-users in the LMRT paper	50
Figure 25:	Bandwidth consumption per household, Italy and selected countries (2012)	55

Tables

Table 1:	Total fixed broadband revenues in billion GBP in selected national markets (2007 and 2012)	40
Table 2:	Compound Annual Growth Rates (CAGRs) for fixed and mobile subscribers in selected countries (2007-2012)	41
Table 3:	CAPEX required to achieve 30 Mbps coverage in Italy (2014)	53

1 Introduction

In recent years, a number of telecommunications network operators have repeatedly raised concerns that the explosive growth of Internet traffic is causing their costs to spiral out of control, to the point where their services may no longer be sustainable.[1]

In this paper, we examine this concern and find that it is not well supported by the data.

While Internet traffic is certainly increasing, there have also been offsetting cost reductions thanks to technological innovation. On fixed networks, the total usage-based cost per user is likely declining, despite the increase in traffic; on mobile networks, although the usage-based cost per user cost is likely increasing, network operators are benefiting both from cost declines, and from offsetting revenue increases.

Overall, we feel that the current data continue to demonstrate that traffic growth is not a root cause of the challenges that network operators face.

Section 2 explains how content providers, consumers, businesses, and ISP networks connect to one another to exchange their traffic, from the perspectives both of technology and of economics. Section 3 discusses current trends as regards the costs and prices of ISP networks today and tomorrow. Where Section 2 is largely based on theory, Section 3 is empirical and quantitative. Section 4 provides a different perspective, explaining the relevance of the economic theory of two-sided markets to the discussion, and discussing the relevance of this discussion to the challenges going forward of funding fibre-based Next Generation Access. Section 5 makes recommendations to industry and to policymakers going forward.

The focus of this paper is not only on Europe, but also on North American and global trends.

1 See for instance PAGE, Mark / ROSSI, Luca / RAND, Colin (2010): “Those who have to build and operate the networks required to carry these traffic volumes earn almost no revenue from [content providers] and are often locked into flat rate price schemes with the [consumers], continually decreasing because of retail competition.” For a more recent expression of similar concerns, see heise online (2014), “Deutsche Telekom: ‘Netzneutralität ist in Wahrheit die Privilegierung großer US-Internetkonzerne‘“,17 September 2014, at: http://www.heise.de/netze/meldung/Deutsche-Telekom-Netzneutralitaet-ist-in-Wahrheit-die-Privilegierung-grosser-US-Internetkonzerne-2392253.html.

2 Connection and interconnection in the Internet

Key Findings

How do network operators carry Internet traffic among one another? How do content providers connect to the Internet, and to you? How does their connection differ from the connection that you have at home or at the office?

The majority of interconnection among Internet Service Providers (ISPs)[2] takes place using variants of either *peering* or *transit*.

Content providers make substantial payments for network connectivity, either through payments to Internet backbone providers, other *Internet Service Providers (ISP)*, and *Content Delivery Networks (CDNs)*, or else through their own investment in equivalent infrastructure. Content providers connect to the Internet in principle in much the same way as other business users; however, large content providers are likely to climb their own "ladder of investment", progressively internalising more and more of the functions of a network operator and/or a CDN.

We find nothing in the existing relationships among content providers and Internet access providers that necessarily implies a free riding problem.

2.1 Peering, transit, and more exotic forms of interconnection among ISPs

If you have a broadband connection at home, you pay an *Internet Service Provider (ISP)* to deliver your data to and from pretty much any Internet location in the world.

Similarly, small businesses and large corporations buy *transit services* from ISPs, and for exactly the same reason. It enables them to communicate with other locations on the Internet.

ISPs need to interconnect with one another as well; otherwise, their respective customers would not be able to communicate with one another. One of the main means by which they do this is, once again, transit. The transit services that one ISP purchases from another (usually better-connected) ISP are not significantly different from those that an enterprise would purchase from the ISP. It is not unusual to find a chain of these transit relationships, where a small or poorly connected ISP is a transit customer of a larger or better connected ISP, which in turn is a transit customer of a large, well-connected ISP.

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2 An Internet Service Provider is a network operator that provides access to the Internet as a service to its customers.

For clarity of exposition, we refer to the ISPs that serve consumers as *broadband ISPs*, and the ISPs that serve large businesses and other ISPs as *commercial ISPs*. It is not unusual for the same company to serve in both roles.

If there were some single super-ISP that ultimately served the whole world, there would be no need for any interconnection arrangements other than transit relationships; however, there are good technical and economic reasons why things are not done in that way. Such a structure would imply a single point of failure,[3] and would also tend to imply a single ISP with monopoly market power.

A second arrangement evolved to interconnect ISPs, especially ISPs of similar size or geographic reach. When two ISPs agree to become *peers*, they agree to interchange traffic, but only for their respective customers (or customers of their respective customers).

There is almost always a charge for transit service, since the ISP is providing a service to its customer. The relationship is asymmetric – the transit customer is not expected to provide the transit provider with transit service to third parties. Peering is, however, a symmetric relationship. If both ISPs feel that they are getting a fair exchange of value, they may (or may not) agree that no money should change hands.[4]

A combination of peering and transit among ISPs would be sufficient to provide a fully connected global Internet (see Figure 1). In the figure, the blue horizontal lines at the top represent peering relationships; all other lines are transit. Each peer forwards traffic only for its own transit customers, and for transit customers of its transit customers; thus, ISP A can communicate with ISP B, and ISPs A1 and A1a can communicate with ISP B1; however, ISP A1 cannot use the peering relationship between ISP A and ISP B to communicate with ISP C1. ISPs A and C must make some other arrangement (for example, an agreement to peer with one another, which is not shown in Figure 1) to ensure that their respective customers can communicate with one another.

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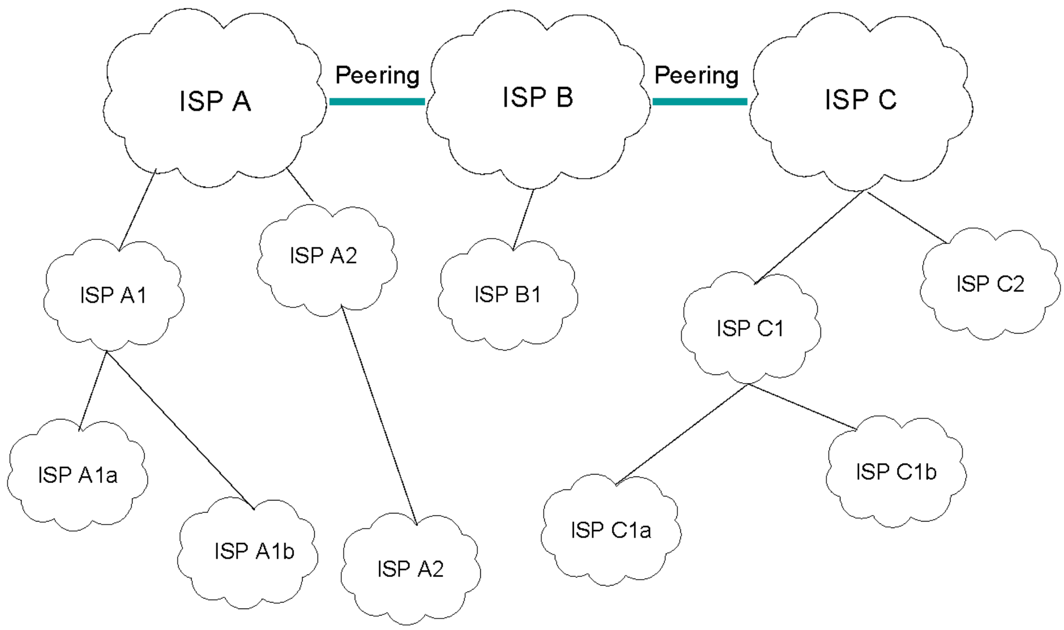
3 In other words, a failure of the single super-ISP would imply a loss of global connectivity.

4 For more rigorous definitions of peering and transit, see Section 2.5 of the "Service Provider Interconnection for Internet Protocol Best Effort Service", a white paper that was produced by NRIC V (the Network Reliability and Interoperability Council V, and advisory group to the US FCC). "Peering is an agreement between ISPs to carry traffic for each other and for their respective customers. Peering does not include the obligation to carry traffic to third parties. … Transit is an agreement where an ISP agrees to carry traffic on behalf of another ISP or end user. … Transit is usually a bilateral business and technical arrangement, where one provider (the transit provider) agrees to carry traffic to third parties on behalf of another provider or an end user (the customer). In most cases, the transit provider carries traffic to and from its other customers, and to and from every destination on the Internet, as part of the transit arrangement. … Peering thus offers a provider access only to a single provider's customers. Transit, by contrast, usually provides access at a predictable price to the entire Internet. … Historically, peering has often been done on a bill-and-keep basis, without cash payments."

Figure 1: Peering and transit relationships



Source: WIK-Consult

Very few ISPs are able, however, to use peering to reach *all* Internet destinations. Even well-connected ISPs typically purchase transit from one or two other ISPs in order to reach destinations that are not covered by their own peering arrangements.

In practice, more complicated variants of peering and transit are also used, and there are some suggestions that these exotic variations are becoming more common over time.[5]

2.2 How content providers invest to deliver their services

In the current debate as to whether content providers should be obliged to make payments to the broadband ISPs that serve the consumers who view their content, it is sometimes asserted that providers of content do not pay for transmitting their data to their customers. The fact is, content providers have always made substantial payments for their connectivity, and we see nothing to suggest that they are, on balance, paying less than they ought to be (see also Chapter 3). We find nothing in the existing relationships among content providers and Internet access providers that necessarily implies a free riding problem.

5 See P. Faratin, D. Clark, S. Bauer, W. Lehr, and P. Gilmore, "The Growing Complexity of Internet Interconnection", Communications & Strategies, number 72, 4th quarter, 2008.

Content providers could be said to be on a *ladder of investment*. As a content provider's traffic, customer base and revenue stream grow, it achieves greater economies of scale. With greater scale, the content provider finds it cost-effective to internalise more and more network and content delivery functions, thus climbing the ladder.[6]

- Small content providers tend to use commercial third party hosting services to host their content, and may use commercial services (such as Amazon) to provide general remote computing application services (e.g. *cloud services*).

- Somewhat larger content providers may choose to deploy their own web hosting capabilities, and to purchase their own transit services from commercial ISPs. They may also find it cost-effective to use a commercial third party *Content Delivery Network (CDN))* such as Akamai or Limelight. The CDN tends to improve performance for the content provider's users, and also to reduce the content provider's expenditures for transit service.[7]

- Still larger content providers make substantial investments of their own in international or global networks. Some content providers peer with ISPs, because that can improve performance and can reduce their need for transit services.

- The largest content providers may find it cost-effective to deploy their own content delivery networks instead of (or in addition to) using commercial CDN services such as Akamai or Limelight.

Different companies make different choices, but the general tendency is to invest more as the content provider's service grows in popularity. For example, Facebook started in a dorm room, and, having grown substantially, broke ground on its first data center in 2010. Google started in a garage, but today (1) hosts its own content, (2) purchases transit, (3) invests in a large global network, (4) peers with many ISPs, and (5) offers its own CDN for deployment within the networks of larger ISPs.

Similarly, Netflix has gone to progressively greater lengths and has apparently made significant development and deployment investments in order to efficiently deliver streaming video to its customers. As recently as 2012, Netflix implemented a complex architecture including the use of Amazon cloud services for *Operational Support Systems (OSS)*, together with caching of video content through three Content Delivery Networks: Akamai, Limelight, and Level3.[8] Today, however, Netflix makes no use of

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6 This is different in its details from the broadband ladder of investment propounded in a series of papers by Martin Cave (see for instance CAVE (2004)), but it is similar in its effects. As an organisation grows, it is motivated to climb the ladder.

7 For background on CDNs, see Gries, C. and I. Philbeck (2013): Marktentwicklung im Bereich Content Delivery Networks (Market developments in Content Delivery Networks), WIK-Diskussionsbeitrag No. 376, April 2013. (German only.)

8 Vijay Kumar Adhikari, Yang Guo, Fang Hao, Matteo Varvello, Volker Hilt, Moritz Steiner and Zhi-Li Zhang (2012), 'Unreeling Netflix: Understanding and Improving Multi-CDN Movie Delivery'.

third party CDNs; instead, Netflix uses three distinct means of delivering its content as close as possible to Netflix's end users, in each case making substantial payments in storage and/or in network transmission capabilities in order to ensure that Netflix customers (who are also customers of their respective broadband ISPs) are able to enjoy a service of acceptable quality. The first is these is through direct peering arrangements with the broadband ISP; the second is through a transit provider such as Cogent or Level 3; and the third is by means of Netflix Open Connect, where Netflix provides embedded CDN cache servers that to the broadband ISPs that serve Netflix end users (as we explain shortly).[9]

Apple appears to be following much the same trajectory as Google and Netflix, and for largely the same reasons. "Apple's online delivery needs have grown in the last few years, driven by its iCloud service for storing users' data and rising sales of music, videos and games from iTunes and the App Store. … The company's need for bandwidth and supporting infrastructure will grow if it moves further into television. … Apple is signing long-term deals to lock up bandwidth and hiring more networking experts, steps that companies like Google … and Facebook Inc. have already taken to gain more control over the vast content they distribute. … Several analysts, however, doubted that Apple could bring all that business in-house overnight. 'It's a natural progression for a company like Apple,' said Aaron Blazar, vice president at telecom consultancy Atlantic-ACM. 'It can take several years.'"[10]

As we have seen in Section 2.1, common practice in the Internet today is for each transit customer to pay for transmitting its data to all destinations on the Internet. This is just as true for commercial enterprise customers as for residential consumers, and it is also true in general for content providers just as it is for other commercial users. The broadband ISPs that serve consumers (not necessarily the same ISPs as the commercial ISPs that serve their content providers) benefit from carrying the content because their customers demand and desire it. The content provider pays to use commercial Internet transit services to deliver a significant fraction of its traffic to end-users. There is no question of free riding here.

As an alternative to purchasing transit services, a content provider that operates an IP-based network could peer with ISPs who agree to do so. Although content providers are not ISPs in the traditional sense (in that they do not necessarily have end-user customers who purchase Internet connectivity directly from them), a number of content providers have invested in building out networks that are comparable to those of the largest ISPs. Content providers of sufficient scale can and do offer and obtain peering arrangements to backbone and access networks worldwide. These are commercially

9 Markham C. Erickson et al. (2014), "Petition to Deny of Netflix, Inc" (in connection with Comcast / Time Warner).

10 Drew Fitzgerald and Daisuke Wakabayashi (2014), "Apple Quietly Builds New Networks: Company Boosts Internet Infrastructure, Lays Groundwork for More Traffic Amid Broader Ambitions", Wall Street Journal, 3 February 2014.

negotiated arrangements where the content provider exchanges traffic with the network operator on a peering basis. Typically, there are no traffic-based charges to either party.

Many of these content providers also connect to Internet Exchange Points (IXPs) around the world. For smaller networks, it is not unusual for the content provider to adopt a liberal peering policy where it offers to peer with almost any network at any of the Internet Exchange Points at which the content provider is present, subject to a basic set of conditions detailed in the content provider's peering policy.

Content providers also invest and innovate in a number of significant ways in order to reduce the impact of their traffic on network operators that carry the traffic to consumers. A noteworthy difference between the peering practices of some content providers and those of commercial ISPs is that, where the content provider and a large commercial or broadband ISP are connected at multiple physical locations, it is not unusual for the content provider to attempt to carry traffic to the interconnection point that is closest to the end-user. In contrast, common practice among ISPs is to hand off traffic at the first available interconnection point ("hot potato" or shortest exit routing). An advisory panel to the US FCC explained that "ISPs use shortest exit routing (also known as 'hot potato' routing). With shortest exit routing, a packet which is to be forwarded via a neighboring ISP is sent via the nearest interconnect to that ISP, without concern for where in the neighboring ISP the destination is actually connected. In other words, the packet will use the interconnect closest to the point where the packet enters the first ISP. If both ISPs use shortest exit routing, the paths that the packets take will not be the same in both directions, even between the same two end points. [Asymmetries of traffic therefore come into play.] … A significant percentage of the traffic in the Internet goes between web users (i.e., personal computers and workstations) and web servers. In general, the volume of traffic from web user to web server is relatively small (consisting of requests for content), and the volume of traffic from web server to web user is relatively large (consisting of the content itself). This implies that in many cases a particular user of the Internet may originate an exchange of data, for example by using their personal computer or workstation to query a web server. However, the system which initiates the exchange is typically the source of only a small percentage of the total traffic, while the web server which is offering a service is typically the source of the bulk of the traffic. Where shortest exit routing is used between ISPs with a similar geographic footprint, this means that the amount of traffic is different in each direction, which may cause one ISP to incur more cost than the other."[11]

These cost asymmetries are the reason why some large ISPs refuse to grant peering where there is a significant traffic asymmetry. Content providers can ameliorate these cost asymmetries, however, by carrying the traffic as close as possible to the point in

11 NRIC V, Focus Group 4 (2001), Interoperability: Service Provider Interconnection for Internet Protocol Best Effort Service. This author was among the drafters of that report. Since the report is not widely available today, relevant parts of the discussion are reproduced in full here. See also J. Scott Marcus (1999), Designing Wide Area Networks and Internetworks: A Practical Guide, Addison Wesley, Chapter 14.

the ISP's network where the user is located. Carrying the traffic closer to the end user serves both to enable a better user experience for the consumer, and also to reduce cost for the commercial or broadband ISP (at a correspondingly increased cost to the content provider).

A second major innovation is that the content provider can offer to deploy servers for its own Content Delivery Network (CDN) into the network of larger ISPs or at large traffic aggregation points aggregation points, such as Internet Exchanges. This tends to bring the content closer to the consumer, which reduces the distance that the data has to travel and the number of routers through which it must pass. This reduction in distance travelled tends in turn to reduce delay, and to provide a better experience for the end-user of the content provider's services.

A few of the largest content providers offer to assume the cost of procuring CDN servers at their own expense, deploying them into the networks of participating ISPs, and operating them.[12] The ISP is expected to provide (1) network connectivity to the CDN servers, and (2) rack space and power in a suitable facility. In most cases, ISPs are happy to agree to these arrangements because they reduce the net cost of network transmission for the ISP – they avoid the need to carry the same data around the ISP's network many times, and reduce the average distance that data travels. Moreover, the customers who benefit from improved response time are customers not only of the content provider, but also of the ISP.

If a content provider offers CDN servers to ISPs, it presumably perceives a new gain in terms of its profitability. It is investing in order to achieve a better experience for its users, and is also reducing costs by reducing carriage of traffic across its own network as well as reducing the payments that it would otherwise be obliged to make for transit services (thus substituting capital expenditures for operating expenditures). If a consumer-serving broadband ISP accepts CDN servers, it is because it perceives economic benefit in doing so, probably in terms of a better experience for its own end-users, and a reduction in net costs. Thus, for a content provider to offer peering or CDN capabilities should not be viewed as a case of free-riding, but rather as a win-win situation (a *Pareto improvement*, with benefits all around) for the ISP, the content provider, and the end-user.

As an example, Google itself functions not only as a content provider, but also as a broadband ISP in a few U.S. cities providing consumers with high speed fibre-based Internet access in a number of cities in the United States (Google Fiber). Google as a broadband ISP considers the use of CDNs on the part of other content providers to be positive for Google Fiber's business case. "We give companies like Netflix and Akamai free access to space and power in our facilities and they provide their own content

12 See, for instance, Netflix (2012), "Announcing the Netflix Open Connect Network", at: http://blog.netflix.com/2012/06/announcing-netflix-open-connect-network.html.

servers. We don't make money from peering or colocation; since people usually only stream one video at a time, video traffic doesn't bog down or change the way we manage our network in any meaningful way — so why not help enable it? But we also don't charge because it's really a win-win-win situation. It's good for content providers because they can deliver really high-quality streaming video to their customers. … It's good for us because it saves us money (it's easier to transport video traffic from a local server than it is to transport it thousands of miles). But most importantly, we do this because it gives Fiber users the fastest, most direct route to their content. That way, you can access your favorite shows faster. All-in-all, these arrangements help you experience the best access to content on the Internet — which is the whole point of getting Fiber to begin with!"[13]

Not all ISPs agree to peer with content providers, and not all agree to accept the CDN servers offered by content providers. This may be their prerogative, but the reasons for such a refusal are not always clear, since the refusal often implies increased costs for the ISP and does not necessarily increase the revenues of that ISP. The content provider would need to serve the same end-user customers, and would presumably send roughly the same volume of data by means of any of its transit providers.[14] It would only rarely be the case that the same ISP that refuses to peer with a content provider subsequently becomes the transit provider to the same content provider. The ISP that refuses to peer would thus end up accepting roughly the same data, either over a peering connection to some other ISP, or else over a transit connection to the ISP's transit provider. In the former case, the ISP may incur additional internal network transmission costs, but derives no additional revenue. A refusal to agree to peering arrangements or a CDN would thus tend to reduce profits both for the ISP in question and for the content provider, and also to result in a poorer customer experience for their mutual end-user.

Where a broadband ISP and a content provider (or an ISP that serves the content provider) cannot come to terms, it is not unusual for the broadband ISP to delay upgrading interconnect capacity, thus allowing performance to gradually degrade as traffic increases over time. Our feeling is that it is preferable, whenever possible, for the parties to reach some commercial agreement rather than holding users hostage to a commercial dispute to which they are not a party.

Different content providers approach their connectivity needs in different ways, but the same analysis will tend to hold in general. Content providers are presumably making payments for transit service that are rational in terms of the costs to which their commercial transit provider ISPs are subject. The broadband ISPs that serve

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13 Jeffrey Burgan (2014), "Behind the scenes with Google Fiber: Working with content providers to minimize buffering", 21 May 2014, at: http://googlefiberblog.blogspot.de/2014/05/minimizing-buffering.html.

14 This is the underlying rationale for the off-net cost pricing principle described in Laffont, Marcus, Rey and Tirole (2003).

consumers (not necessarily the same ISPs as those that serve their content providers) benefit from carrying the content because their customers demand and desire it.

None of these arrangements necessarily implies a free riding problem. In each case, the content provider can be assumed to be investing appropriately, either in infrastructure or in Internet transit service.

2.3 Conclusions

Internet Service Providers (ISPs) connect to consumers, to businesses, and to content providers under generally similar technical and economic arrangements. The payments and investments that large content providers make are not necessarily different from or less than the payments and investments that other business users of similar size would make.

Disputes between content providers (and the commercial ISPs that serve them) and consumer-facing broadband ISPs have occurred from time to time in the past, and will continue to occur in the future. Disputes like these involve difficult fact-specific determinations that will not necessarily lead to simple or unambiguous answers. What will be important going forward is that disputes do not impede the ability of consumers to view the content that they wish over the networks that they have chosen.

3 Understanding network costs and network prices

Key Findings

Traffic volumes for Internet Protocol (IP) traffic are increasing, both for fixed and for mobile networks, but the percentage rate of traffic increase year over year is declining over time.

The growth in traffic reflects not only an increase in traffic per subscriber, but also an increase in the number of subscribers. The number of fixed broadband subscribers continues to increase, as does the number of mobile users who use data services.

Unit costs for relevant network equipment such as routers and optoelectronics are declining at a rate equal to or greater than that of Internet traffic increase per user in the fixed network. This can be viewed as an example of Moore's Law.

In both the fixed and mobile European networks that are the primary focus of this study, prices seem to respond to changes in underlying costs, as they should in competitive markets.

For the fixed network:

- The positive unit cost impact of Moore's Law price/performance improvements is now marginally greater than the negative unit cost impact of traffic growth per user.
- Broadband prices appear to be declining slightly.

For the mobile network:

- The positive unit cost impact of Moore's Law price/performance improvements appears to be significantly smaller than the negative unit cost impact of traffic growth per user.
- Effective prices have increased substantially.

If individual companies find it difficult to raise prices due to competition, this is not a market defect. The most likely explanation is that their costs are higher than those of their competitors. Costs and revenues are growing in balance with one another overall.

A key claim that this study seeks to address is that costs are rapidly increasing for network operators, but that retail prices for consumer broadband for some reason cannot respond.

A number of factors need to be considered in assessing that claim, all of which are amenable to some degree to objective quantitative and empirical analysis, in terms of their historical behaviour and also of likely future trends. To an economist, the *price* and *quantity* of goods or services tend to be key, as they are here.

- What is the historical and likely future tendency of the quantity of service demanded over the Internet (expressed here primarily in terms of network traffic)?

- What is the historical and likely future tendency of unit prices for the cost drivers that influence the retail price?

- What indications are there that the retail price for broadband Internet access can, or cannot, increase in response to a net increase in underlying costs?

There is no question that Internet traffic is increasing – but this is nothing new. Internet traffic has been increasing for as long as there has been an Internet. It is equally clear that the unit cost of most of the goods and services used to produce broadband Internet access are declining.

The question, then, does not depend solely on whether Internet traffic is increasing. Rather, it depends on whether the increase in traffic is faster than the decline in the underlying unit costs of carrying that traffic.

This question is, as it happens, not a new one. Both practitioners and academic experts have long understood that there was something of a race between the growth in Internet traffic and the cost reductions driven by improvements in semiconductor technology (see the discussion of Moore's Law in Section 3.3). In a 2001 paper, for instance, Coffman and Odlyzko (looking at traffic growth that in percentage terms was far more rapid than what we experience today) noted that "Since computing and storage capacities will ... be growing, as predicted by the versions of 'Moore's Law' appropriate for those technologies, we can expect demand for data transmission to continue increasing. A doubling in Internet traffic each year appears a likely outcome.[15] … Such a growth rate would have several important implications. In the intermediate run, there would be neither a clear 'bandwidth glut' nor a 'bandwidth scarcity,' but a more balanced situation, with supply and demand growing at comparable rates."[16]

We also note that, in assessing these factors, it is important to distinguish between *growth in the number of subscribers* and *growth in the traffic per subscriber*. They have quite different effects on the revenue and profitability of network operators. A new subscriber is generally associated with a new revenue stream. New subscribers might tend to have lower *willingness to pay (WTP)* than existing subscribers (otherwise they would have joined sooner), but they might also make less use of the network and thus generate less traffic. In the abstract, then, the ratio between costs and prices for new consumers would not necessarily be very different from the ratio for existing customers.

15 A doubling year over year may have appeared likely in 2001, but rates of traffic growth today are far less, as we explain shortly.
16 Coffman/Odlyzko (2001).

Section 3.1 provides a general overview of the relationships between price and cost as they relate to the matter at hand. Section 3.2 notes the distinction between usage-based costs, which are directly relevant to the discussion, and fixed costs, which for the most part are not. Section 3.3 summarises Moore's Law and its relevant effects. Section 3.4 reviews trends in a number of key underlying relevant cost drivers of an Internet network operator. Section 3.5 explains overall trends in Internet protocol traffic, while Section 3.6 explains the corresponding trends in the number of Internet subscribers. Section 3.7 integrates the material in the previous two sections, presenting traffic per user, which is a normalised measure of the key alleged driver of cost. Section 3.8 explores trends in retail pricing, and their relevance for overall revenue for the network operator. Section 3.9 then closes with findings and conclusions.

3.1 Costs and prices

Key Findings

In a conventional competitive market, marginal cost tends to set a floor for retail prices, while the prices established by competitors effectively set a ceiling.

Before embarking on an analysis of costs and prices for transmission over the Internet, it is useful to review the general economic principles that link costs to prices.

In an effectively competitive market, prices tend in general to move in response to underlying costs. The short run marginal cost sets a lower bound to the price,[17] while the prices established by competitors effectively set a ceiling. The difference between the cost and the price is the producer's profit.

There are exceptions. Under some circumstances, a producer maintains some *pricing power*[18] – the ability to price significantly in excess of its costs. A firm that benefits from strong *brand recognition* may benefit from some degree of pricing power. *Price and/or quality discrimination* (as for instance occurs when an airline distinguishes between first class and second class tickets) can also confer some pricing power.

Market power can enable a firm to price above the competitive level that would otherwise prevail – if there are no competitors, or if the competitors are relatively ineffective, then they do not fully constrain the price that a monopolist firm can set. This tends not to be a factor in terms of retail broadband in Europe, however, because effective regulation at wholesale level results in reasonable competition at retail level in

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17 To an economist, the cost of capital employed to produce the good or service is also part of this cost.

18 We refer here to pricing power as in HOTELLING (1929). It is largely a function of consumer willingness to pay, and not necessarily indicative of a market failure.

most European Member States. In the United States, by contrast, consumers typically have fewer options, particularly for service at higher speeds.

Consumers buy a service if the benefit that they derive is worth more to them than the price. The difference between their valuation and the price is their *consumer surplus*. The higher the price, the less their surplus. If the price were increased, then consumers purchase less of the service. If the price were increased so much that the consumer surplus goes negative, then consumers are not motivated to purchase the service at all. This response of consumer demand to price is termed the *price elasticity of demand*.

The linkage between price and cost for broadband access is complicated. Network operators tend to have somewhat different cost structures. Consumers may value network connectivity somewhat differently, and thus one consumer may have different willingness to pay than another. The consumer's choice of provider is of course influenced by the network operator's *price*, but not by its underlying *costs*.

Nonetheless, if one wants to understand prices, it is important to understand the underlying costs and cost drivers. First, the underlying marginal cost to which a network operator is subject tends to set a floor for that operator's price. Second, to the extent that the market is competitive, the prices charged by aggressive competitors will tend to limit the prices that can be charged by other network operators.

3.2 Fixed costs versus usage-based costs

Key Findings

Our concern in this study is with the impact of increased Internet traffic on network costs. Not all network costs are relevant to this question. Our focus in this study is on *usage-based costs and cost drivers*, not on fixed costs.

Data from the BNetzA, the German National Regulatory Authority (NRA), shed light on the relative magnitude of these costs.

- Transport in the IP backbone network contributes just € 0.72 of monthly cost, or 2.8% of the monthly total, and this percentage is rapidly declining over time.
- Transport in the concentration network contributes just € 2.00 to monthly costs, or 7.7% of the monthly total.
- The combined usage-based costs for a broadband interface were found to represent just 10.3% of the total cost.

These usage-dependent costs are dwarfed by the cost of the unbundled copper local loop and by other costs that may be dependent on the number of subscribers, but that are largely or fully independent of the level of usage per subscriber.

In this study, we are concerned with the impact of increased Internet traffic on network costs. Not all network costs are relevant to this question.

There is a long European and global tradition of regulatory cost modelling. It is routine to distinguish between *fixed costs* and *usage-based costs*. Clearly, it is the usage-based costs that are relevant here, since those are the costs that depend on the level of Internet traffic.

For example, a large fraction of the cost of the fixed network is associated with the last mile. The physical line is typically ordered once (or upgraded at rare intervals), whether it is copper twisted pair, cable, or fibre, and then maintained for long periods of time as the electronics that drive the line are upgraded over time. The cost of civil works (especially digging) represents a large fraction of the cost of the line. More significantly, however, it is the end user who chooses the speed of the broadband connection; in order to maintain a rational system of incentives, it should therefore be the end user who bears the cost. These costs are therefore not relevant to the discussion of the impact of increased traffic on the costs of network operators.

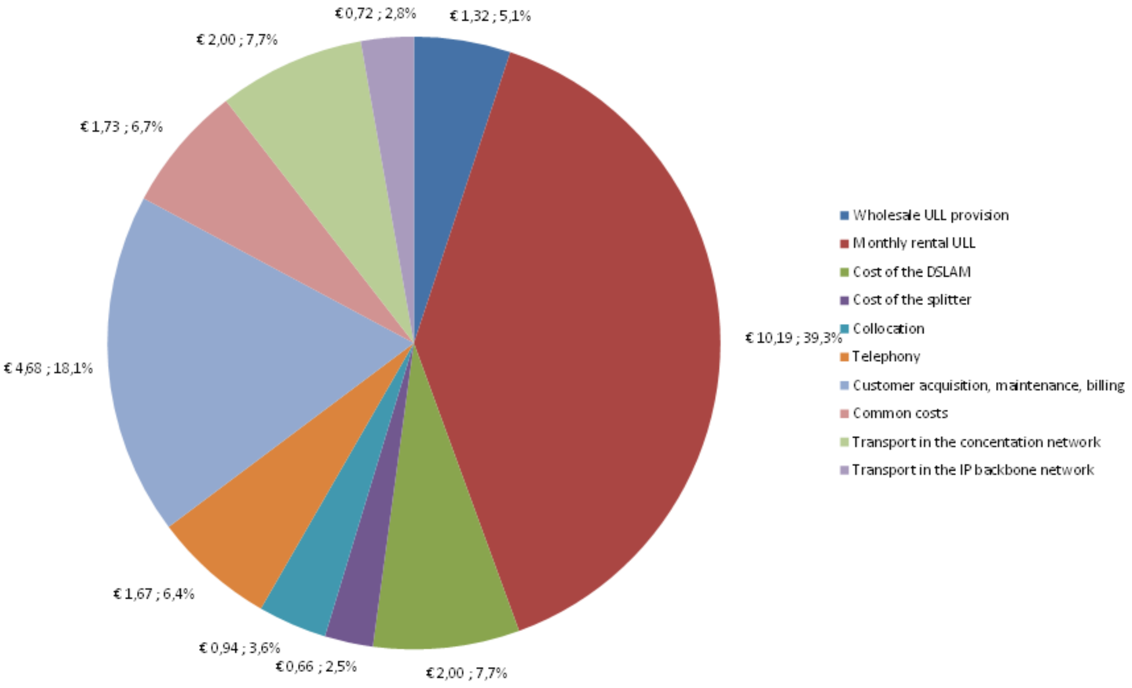
Many operational costs are a function of the number of customers, and largely independent of the level of traffic. For instance, costs associated with customer acquisition, customer care, billing, and bad debt would appear to have little or nothing to do with the volume of Internet traffic over the broadband connection.

For a fixed broadband service, it turns out that the usage-based costs represent a tiny fraction of the total. Data from the BNetzA, the German National Regulatory Authority (NRA), shed light on the magnitude of these costs. In a 2013 proceeding,[19] the BNetzA found that:

- Transport in the IP backbone network contributes just € 0.72 of monthly cost, or 2.8% of the monthly total (see Figure 3).
- Transport in the concentration network contributes just € 2.00 to monthly costs, or 7.7% of the monthly total (again, see Figure 3).
- The combined usage-based costs for a broadband interface thus correspond to just 10.3% of the total cost.

19 BNETZA (2013), Beschluss in dem Verwaltungsverfahren BK 3c-13/002/E19.02.2013, 26 June 2013.

Figure 2: Monthly cost elements of a bundled DSL broadband/voice service (2013)



Source: Data from German BNetzA (2013), page 80; WIK calculations[20]

In our previous 2011 study, these figures were 7% and 6%, respectively, based on a 2009 BNetzA proceeding.[21] Numerous European NRAs confirmed that those percentages were consistent with their experience at the time. Due to the subsequent, continuing decline in Internet transit prices (see Section 3.4.2), the percentage contribution of transport over the IP backbone to total cost declined briskly from 7% to 2.8% in the four years from 2009 to 2013.

These usage-dependent costs are dwarfed by the fixed and sunk cost of the unbundled copper local loop and by other costs that may be dependent on the number of subscribers, but that are largely or fully independent of the level of usage per subscriber.

20 Ibid.
21 BNETZA (2009): Beschluss in dem Verwaltungsverfahren BK 3c-09-005/E20.01.09, 31 March 2011.

3.3 Moore's Law

Key Findings

Unit costs for relevant network equipment tend to decline over time. This can be viewed as an example of Moore's Law.

In a famous 1965 paper, Gordon Moore recognised that the number of components that could cost-effectively be implemented with a single integrated circuit was doubling per unit time.[22] Today, it is widely understood that, with present technology, the number of components per integrated circuit approximately double every two years.[23] This doubling every two years continues to the present day (see Figure 4).

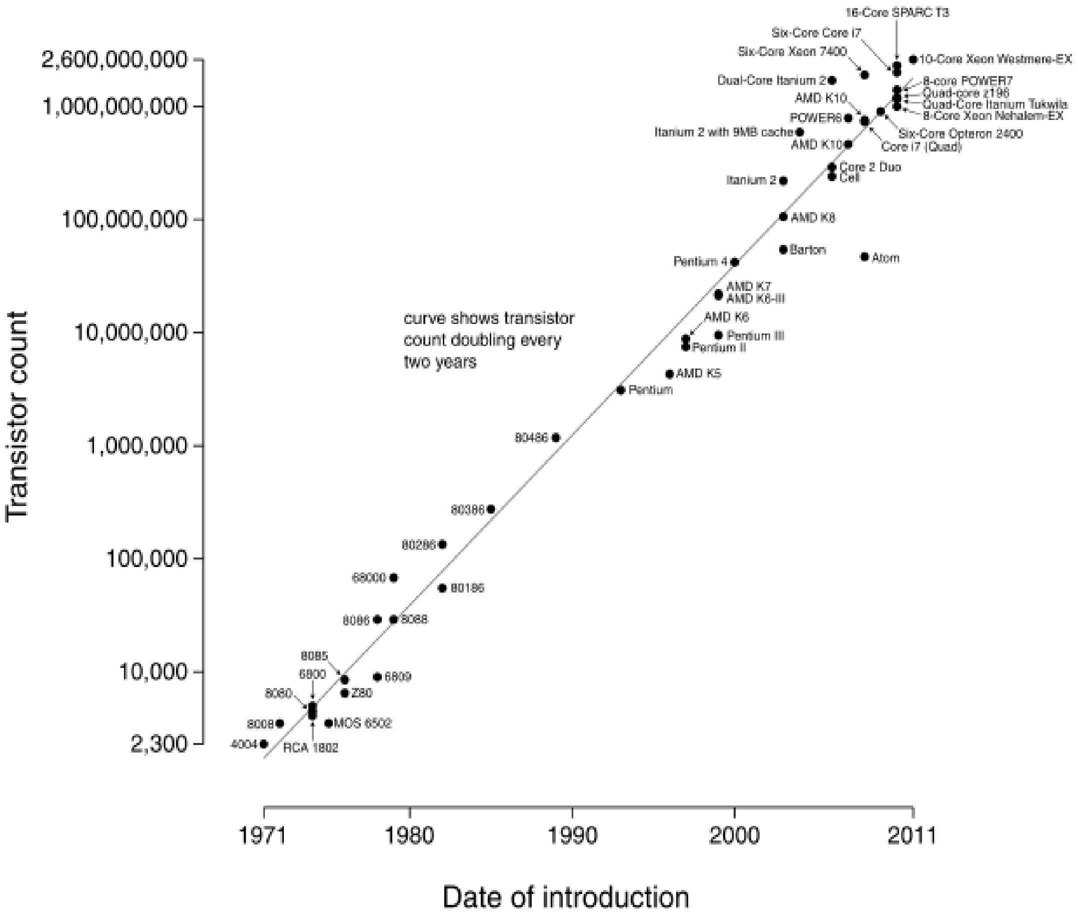
We are all familiar with the effects of Moore's Law. If we buy a personal computer today, it will cost no more than a personal computer that we could have bought two years ago, but it will be twice as fast, will have twice as much memory, and will likely have a hard disk drive (or semiconductor equivalent) that is twice as large.[24]

22 Gordon Moore, "Cramming more components onto integrated circuits", Electronics, Volume 38, Number 8, April 19, 1965. The original paper suggested a doubling per year, but subsequent work found the rate to be a doubling every eighteen to twenty-four months.

23 Fundamental physical limits will eventually put a limit to trend, but it is likely to continue for a few more cycles at least.

24 Disk storage is also benefiting from rapid improvements in technology.

Figure 3: Microprocessor Transistor Counts 1971-2011 & Moore's Law



Source: Wikipedia[25]

Improvements in the cost-effectiveness of network equipment due to technological improvement can compensate for, or even exceed, the rate of increase in Internet traffic. These Moore's Law improvements relate to routers, for example, but similar improvements are visible in opto-electronic gear that drives fibre optics – the number of wavelengths that can be distinguished over a single fibre is also steadily increasing over time. Rapid technology-driven improvements in price/performance are also visible in rotating magnetic disk storage. There are also dramatic improvements in the efficiency with which data can be transmitted over the air.[26]

25 Moore's law. (2011, July 23). In Wikipedia, The Free Encyclopedia. Retrieved 06:56, July 24, 2011, from http://en.wikipedia.org/w/index.php?title=Moore%27s_law&oldid=440998745. Figure by Wgsimon.

26 This assumes that national spectrum management authorities have made sufficient spectrum available. See RYAN (2005).

3.4 Trends in relevant unit costs

Key Findings

The observed Moore's Law declines in unit costs for relevant network equipment are substantial. For high capacity routers, we estimate a CAGR of -26.4%; for long haul DWDM, a CAGR of -18.4% over the period 2006-2013 (see Section 3.4.1).

The decline in the unit price of international Internet transit – a highly competitive market in many European capitals – is a direct result of the decline in the unit prices that network operators pay for underlying components, including high capacity routers, optoelectronics, undersea cable capacity and long distance circuits over land (see Section 3.4.2).

These declines in unit costs benefit the backhaul networks of both fixed and mobile network operators.

The cost drivers of the mobile network airlink are also benefitting from technological improvements; however, the last mile of fixed networks does not benefit in the same way.

The cost of a fixed copper line has been relatively stable, but the amount of data that can be carried at a reasonable cost is increasing. These last mile fixed networks costs are only marginally relevant to the question of the impact of increasing traffic on costs, however, since the cost of the line is largely independent of the traffic carried.

This section considers the evolution over time of the cost drivers for the fixed and mobile Internet network core, the fixed last mile, and the mobile air interface.

3.4.1 Unit costs for equipment in the network core

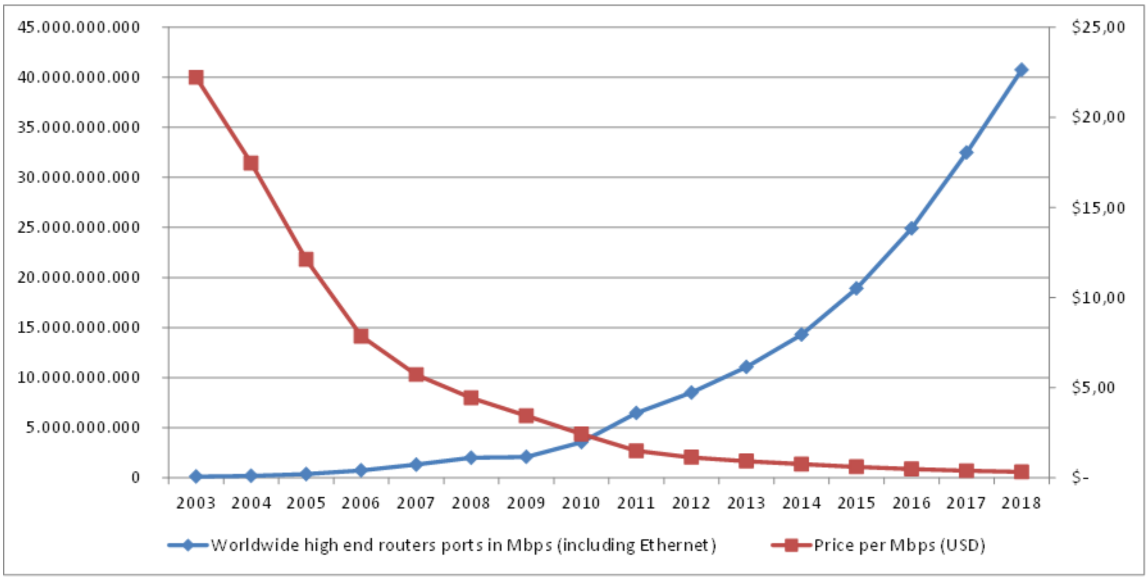
Unit costs in the core of the Internet have been rapidly declining over the past ten years due to Moore's Law improvements in the price/performance of high capacity routers and DWDM optoelectronic equipment.

The high capacity transit that is sold to large enterprises and to large ISPs is to a significant degree a commodity product in a highly competitive marketplace; consequently, it is possible to reliably infer cost trends from price trends. There is ample evidence of a steady decline in the price / Mbps of Internet transit (see Section 3.7). We would therefore reasonably expect to find a drop in unit costs for the elements that the IP transit providers use to provide the service, and this is indeed the case.

This trend can be assumed to reflect the aggregate behaviour of all of the usage-sensitive cost drivers of the transit service, including (1) high capacity routers, (2) optoelectronics, (3) undersea cable capacity, and (4) circuits over land. Labour costs obviously play a role in these prices, but they are not particularly relevant here, since they can be assumed to be driven by the number of customers rather than by the volume of traffic that each customer uses – they are for the most part not *usage-dependent*.

Detailed analysis bears these intuitions out. Market research data[27] show that the price per Mbps of capacity in high end service provider routers and in long haul DWDM equipment continue to fall at a brisk pace. Figure 5 depicts the falling unit cost trend (expressed in USD per Mbps of capacity shipped) for high capacity routers, while Figure 6 does the same for long haul DWDM equipment. We derived these estimates by taking the historical or projected total worldwide value of shipments and dividing it by the total port capacity shipped worldwide, in Mbps.

Figure 4: Price per Mbps (USD) and shipment quantities for high end routers

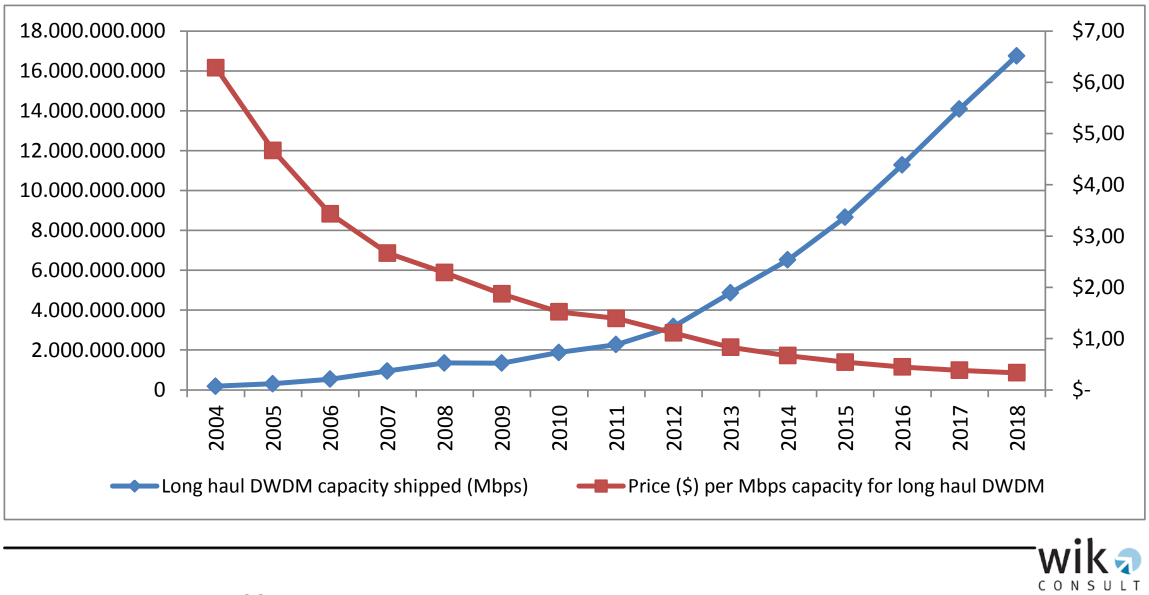


Source: Dell'Oro data,[28] WIK calculations

27 Dell'Oro is a respected firm that routinely conducts detailed market research on the communications industry. Our analysis of both historical and future trends are based on Dell'Oro data.

28 Dell'Oro Group, Routers Report: Five Year Forecast: 2011 – 2015, Vol. 15, No. 2 R2A, Customer Segments: Enterprise Routers, Service Provider Routers, published July 2011.

Figure 5: Price per Mbps (USD) and shipment quantities for long haul DWDM



Source: Dell'Oro data,[29] WIK calculations

Note that the volume trend and the unit price trend are opposite in direction; however, they are not equal in magnitude. The historical CAGRs reflecting the decline in the unit price of high end routers and long haul DWDM over the period 2006-2013 are -26.4% and -18.4%, respectively. The CAGR of high end router shipments (not all of which go to network operators) over the same period is 47.6%, while that of long haul DWDM shipments is 37.1%. The total revenue of equipment manufacturers (not all of which derives from equipment manufacturers) increases over time, but not nearly as much as the growth in capacity alone would suggest.

3.4.2 Internet transit costs

In Section 3.2, we found that the cost of transport in the Internet Protocol (IP) backbone network was one of the two main components of usage-based cost, together with the cost of transport in the concentration network (i.e. to bring traffic to the point where it can be said to enter the IP backbone).[30]

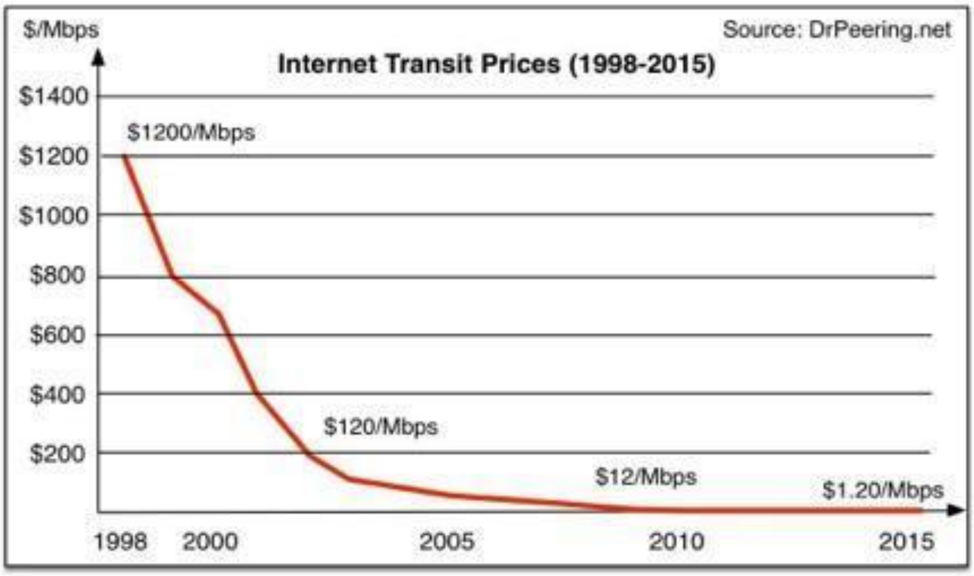
Numerous sources find rapidly declining unit prices for Internet transit (see, for example, Figure 7, which shows a factor of ten decline every four or five years). This rough

29 Dell'Oro Group, Optical Transport Report: Five Year Forecast: 2011 – 2015, Vol. 11, No. 2 O2A, Technology Segments: WDM, Multiservice Multiplexer, Optical Switch, Optical Packet, published July 2011.

30 The cost should be no higher, irrespective of whether the network operator purchases IP transit from a third party or self-supplies. Unless the network operator has made an irrational build-versus-buy decision, the cost to self-supply should not be greater than the price to purchase from a third party.

estimate by a U.S.-based expert implies an even faster decline than we computed in our 2011 study,[31] which saw the unit price of Western European 10 Gigabit Ethernet transit service declining with a CAGR of -27%, which would imply a factor of ten reduction every seven years.

Figure 6: Estimated IP transit prices in USD / Mbps (1998 - 2015)



Source: William B. Norton (Dr. Peering)[32]

For many years, Telegeography has been providing detailed historical data of IP transit volumes, prices, and revenues by country and region. They report that "[t]he IP transit market generated $2.1 billion in revenues in 2013. Sales of circuits connecting customers to Internet hubs contributed an additional $2.5 billion, for a total of $4.6 billion in revenues."[33]

Telegeography's forecast of worldwide transit revenues going forward depends somewhat on the degree to which traffic shifts from transit to peering, which has been ongoing over the past few years. If present trends continue, they predict "that IP transit-related revenues will fall from $4.6 billion in 2013 to $4.1 billion in 2020. If the ratios of

31 J. Scott Marcus and Alessandro Monti (2011), "Network Operators and Content Providers: Who Bears the Cost?", 13 September 2011, available at: http://ssrn.com/abstract=1926768.

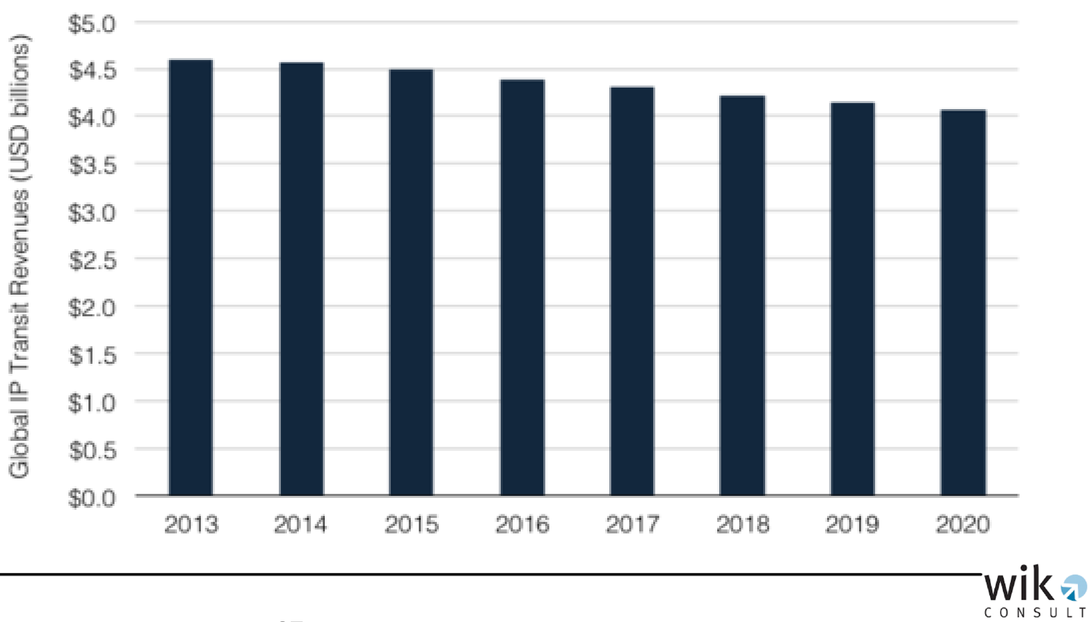
32 William B. Norton („Dr. Peering") (2014), "Internet Transit Tricks", 30 April 2014, at: http://drpeering.net/AskDrPeering/blog/articles/Ask_DrPeering/Entries/2014/4/30_Internet_Transit_Tricks.html.

33 Telegeography (2014), IP Transit Revenues, Volumes Dependent on Peering Trends, 8 July 2014, at: http://www.telegeography.com/press/marketing-emails/2014/07/08/ip-transit-revenues-volumes-dependent-on-peering-trends/index.html.

traffic routed via transit and peering were to stabilize at current levels, IP transit revenues would increase to $5.5 billion by 2020."[34]

In a 2011 study,[35] we found that the total cost to convey all European Internet traffic by third party transit was fairly stable (and possibly declining) from year to year, and moreover was surprisingly small. Current Telegeography data tend to continue to support both claims (see Figure 8). Total global transit revenues are indeed small, and appear to declining over time, *despite the growth in Internet traffic*.[36]

Figure 7: Global IP transit revenues (2013-2020)



Source: Telegeography (2014)[37]

A related trend worth noting is that an increasing fraction of Internet traffic is remaining local due to the use of caching and *Content Delivery Networks* (*CDNs*), especially for video content. This traffic never requires IP transit at all. Cisco estimates that "[i]n 2013, total metro traffic was 2.0 times higher than long-haul traffic, and by 2018, metro traffic will be 2.6 times higher than long-haul."[38] This trend also tends to reduce the total cost of IP backbone transit.

34 Ibid.
35 J. Scott Marcus and Alessandro Monti (2011), "Network Operators and Content Providers: Who Bears the Cost?", 13 September 2011, available at: http://ssrn.com/abstract=1926768.
36 Telegeography (2014), IP Transit Forecast Service, 8 July 2014, at: http://www.telegeography.com/research-services/ip-transit-forecast-service/. The network operators obviously make additional expenditures to self-supply transit, but unless the ratio of self-supply to third party supply were to drastically change, the downward trend in total expenditure should be similar.
37 Ibid.
38 Cisco (2014), The Zettabyte Era: Trends and Analysis, 10 June 2014.

3.4.3 Effects at the edge of fixed and mobile networks

Moore's Law, and technologically driven improvements in general, operate with different strength in different portions of the network, and also operate somewhat differently for fixed networks in comparison with mobile networks.

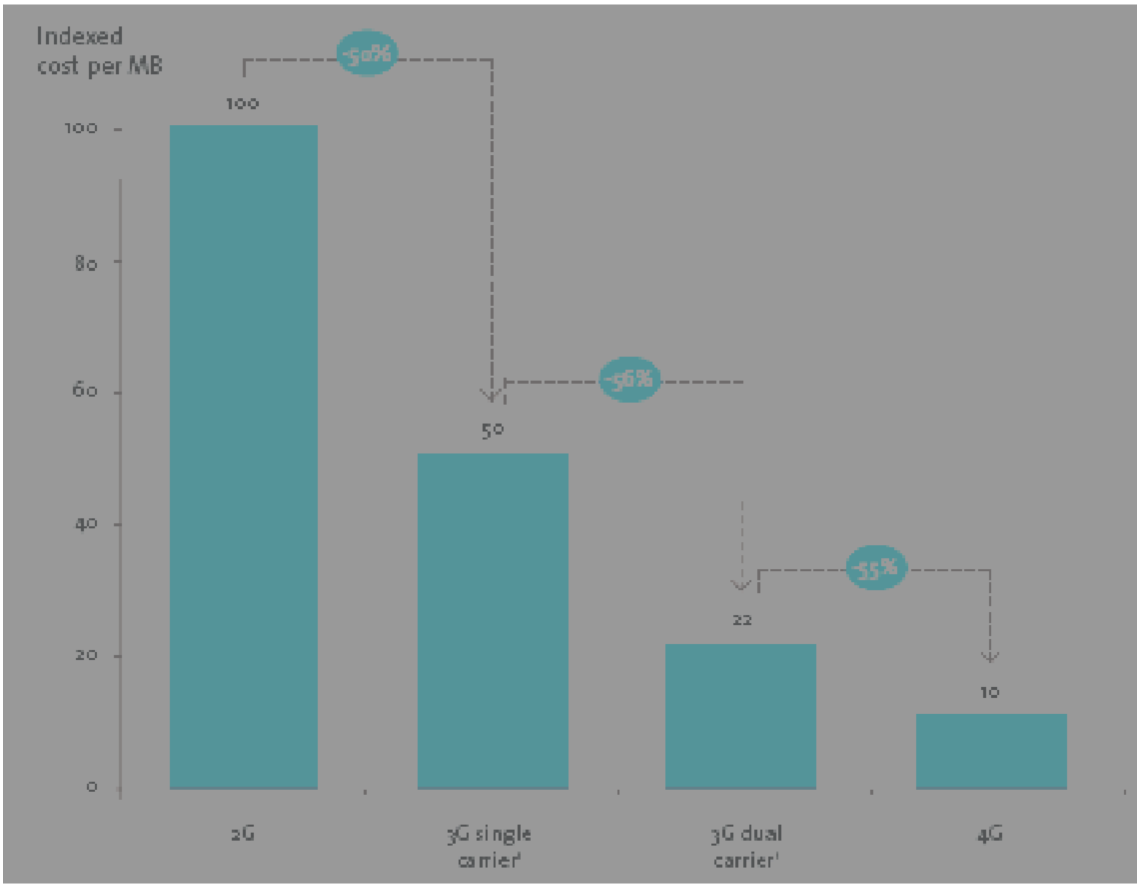
Moore's Law has much less impact on the last mile of the fixed network than on the core. This is only a secondary consideration in this study, since our focus is on usage-based costs rather than fixed costs (see Section 3.2); nonetheless, a few remarks are in order. The cost of fibre cabling is declining only slowly over time, while the cost of copper cabling is increasing. Labour costs are not declining. The cost of trenching cable, and more generally the cost of civil works, may be benefiting somewhat from improved techniques but are not showing the kind of rapid improvement that we are witnessing in semiconductors. At the same time, the use of improved technology means that far more data can be transmitted over the same copper cable (whether for telecommunications of for cable television), due not only to improvements in last mile technology, but also in the technology employed in the back-haul network. Thus, the cost of connecting a house is changing only slowly over time, but the amount of data that can be carried over the connection is increasing.

Replacement of copper cable with fibre cable represents a quite substantial one-time expense, but provides an enormous increase in capacity.

Putting all of this together, the cost per million bits (Megabit) per second (Mbps) in the core of both fixed and mobile networks is declining rapidly due to Moore's Law (as we demonstrated in Sections 3.4.1 and 3.4.2).

For the edge of the mobile network, the cost per Mbps over the airlink is also declining rapidly (see Figure 9), but probably not as rapidly as the increase in traffic per user. These costs are relevant, because they are traffic-dependent.

Figure 8: Advanced mobile technology significantly lowers unit costs



Source: BCG, "Reforming Europe's Telecoms Regulation to Enable the Digital Single Market"[39]

39 BCG (2013), "Reforming Europe's Telecoms Regulation to Enable the Digital Single Market", 11 July 2013. BCG notes that 3G dual carrier is the natural evolution of 3G single carrier allowing the user to connect to two cells at once to increase peak data rates and improve utilization of available resources and quality of service especially in areas with weak radio reception.

3.5 Trends in traffic volumes

Key Findings

Traffic volumes for Internet Protocol (IP) traffic are increasing, both for fixed and for mobile networks; however, the percentage growth rate of traffic increase year over year is declining over time.

The increase in traffic is partly a function of an increase in the number of subscribers, and partly a function of an increase in traffic per subscriber.

There is no question that the Internet has experienced tremendous growth in traffic volumes in recent years. Over the years, there have been many predictions about the rate of growth of Internet traffic, many of them far off the mark.[40] How much is traffic really growing, and how will growth rates in traffic develop in the coming years?

As with any prediction, there are inevitable uncertainties. Growth patterns depend on many factors, including macro-economic developments. A period of economic boom could stimulate Internet traffic and growth, just as a period of economic downturn could depress it.

A number of firms now provide reasonably credible forecasts of the growth of Internet traffic in the coming years. While forecasts differ, Cisco Systems provides a forecast that is respected and widely cited. The Cisco VNI forecast is built on analyst projections and actual usage reports, and is verified after the fact using real network data.[41]

Multiple sources, Cisco among them, suggest that Internet traffic is unlikely to grow in the future as it did in the past.

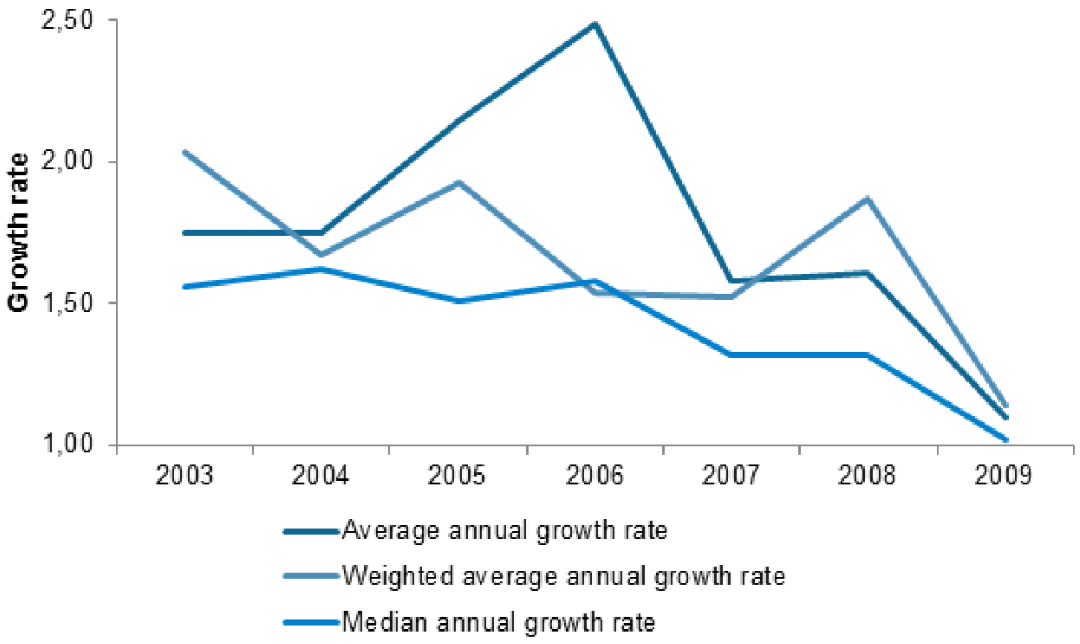
It is useful to begin by looking at historical trends. Ten to fifteen years ago, Internet traffic as a whole grew more than 100% annually, but has since slowed down to a more moderate pace. The absolute volume of traffic has continued to increase, but the rate of traffic growth is clearly declining. The Minnesota Internet Traffic Studies (MINTS) project, overseen by the respected expert Andrew Odlyzko, finds a clear historical trend of decreasing growth rates in Internet traffic (see Figure 9).[42]

40 Claims that Internet traffic was doubling every 100 days might have been correct for a single year (1995), but led to the overly optimistic belief that such growth rates would persist indefinitely (see Odlyzko (2003), p. 5).

41 Cisco (2014), “Cisco Visual Networking Index: Forecast and Methodology, 2013–2018”, 10 June 2014, available at http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.pdf.

42 See http://www.dtc.umn.edu/mints/.

Figure 9: Internet backbone traffic growth rates



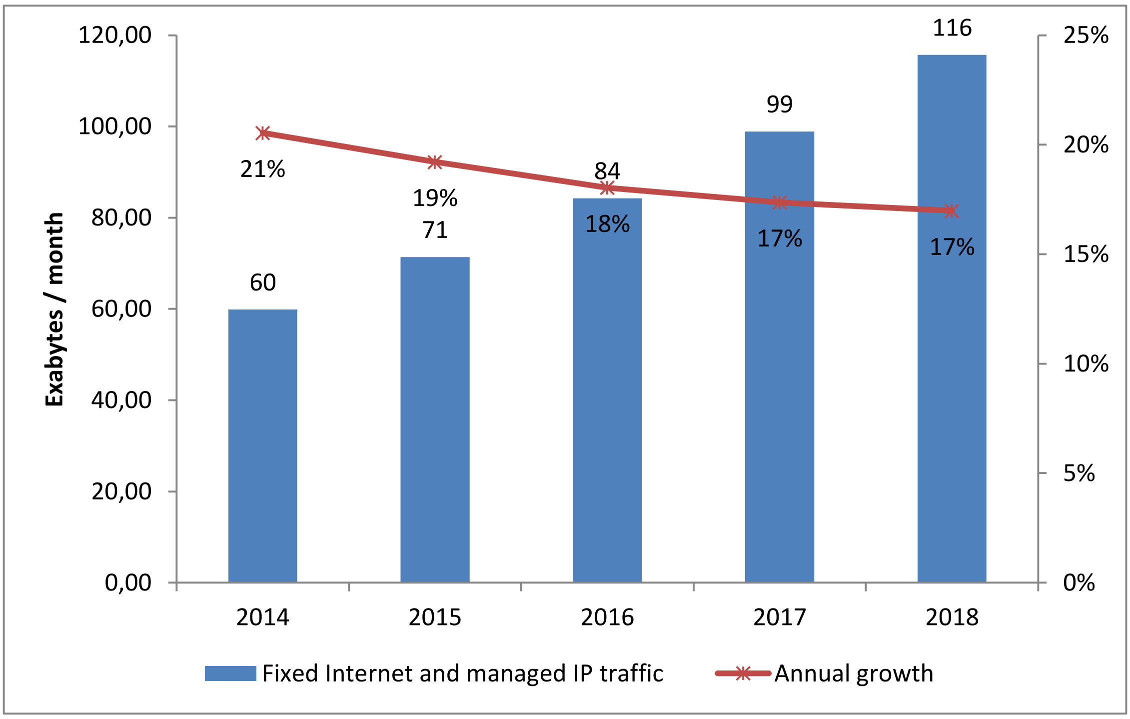
Source: MINTS[43]

It is clear that historical growth rates in Internet traffic are diminishing rather than increasing. What overall growth should we expect in the years to come? The Cisco VNI forecast provides a useful indication overall (see Figure 10). Global fixed Internet and managed IP[44] traffic is expected to grow from a volume of 59.9 Exabytes per month in 2014 to a volume of 115 Exabytes per month in 2018, but the annual rate of growth of IP traffic year over year is expected to decline slightly from 21% in 2014 to just 17% in 2018; moreover, these rates of growth are modest in comparison with Cisco VNI forecasts of just a few years ago.

43 See http://www.dtc.umn.edu/mints/home.php.

44 Cisco defines managed IP traffic as constituting including "corporate IP WAN traffic and IP transport of TV and VoD". "Managed IP video is IP traffic generated by traditional commercial TV … This traffic remains within the footprint of a single service provider, so it is not considered Internet traffic." Cisco (2014), Cisco Visual Networking Index: Forecast and Methodology, 2013–2018, 10 June 2014.

Figure 10: Cisco VNI forecast of global fixed Internet and managed IP traffic in Exabytes per month and associated growth rates (2014-2018)



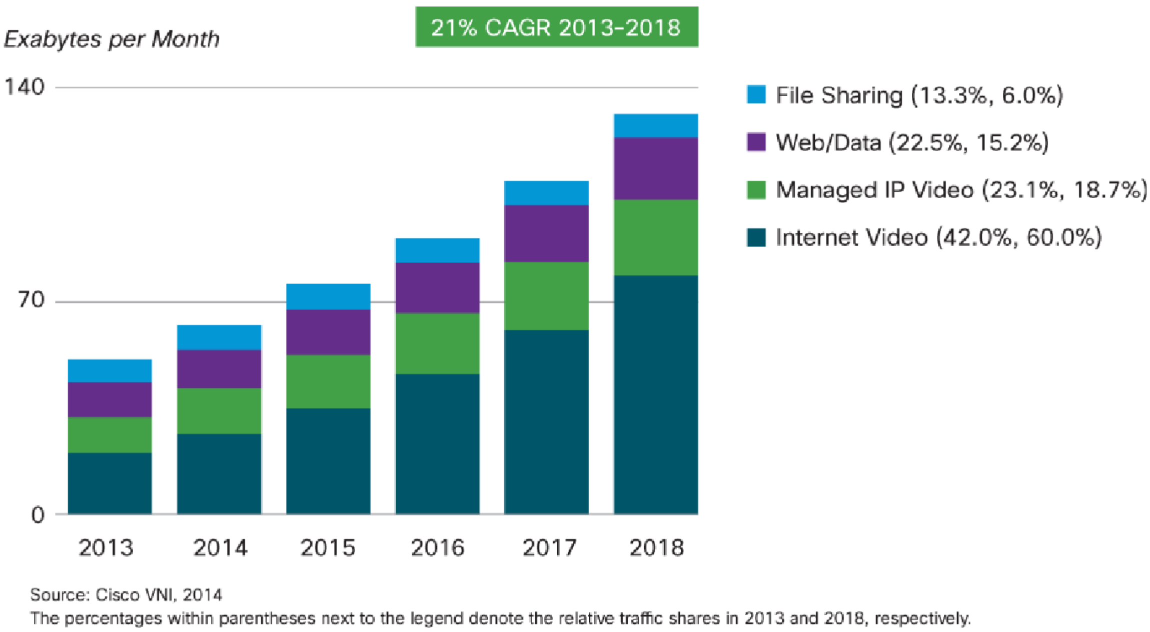
Source: Cisco VNI online database (2014),[45] WIK calculations

Many different factors are likely to contribute to traffic growth, including growth in the number of smartphone and tablet users, increasing broadband speeds, cloud computing, eHome, eHealth, HD-TV, and 3D video. Cisco is, however, of the view that video plays the dominant role in traffic growth going forward. "The sum of all forms of IP video, which includes Internet video, IP VoD, video files exchanged through file sharing, video-streamed gaming, and videoconferencing, will continue to be in the range of 80 to 90 percent of total IP traffic. Globally, IP video traffic will account for 79 percent of traffic by 2018".[46] Video is thus the largest driver of Cisco's estimate of 21% Compound Annual Growth Rate (CAGR) in bytes of traffic per month (see also Figure 11).

45 See http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html#~overview.

46 Cisco (2014), The Zettabyte Era: Trends and Analysis, 10 June 2014.

Figure 11: Global IP traffic by application category (2013-2018)

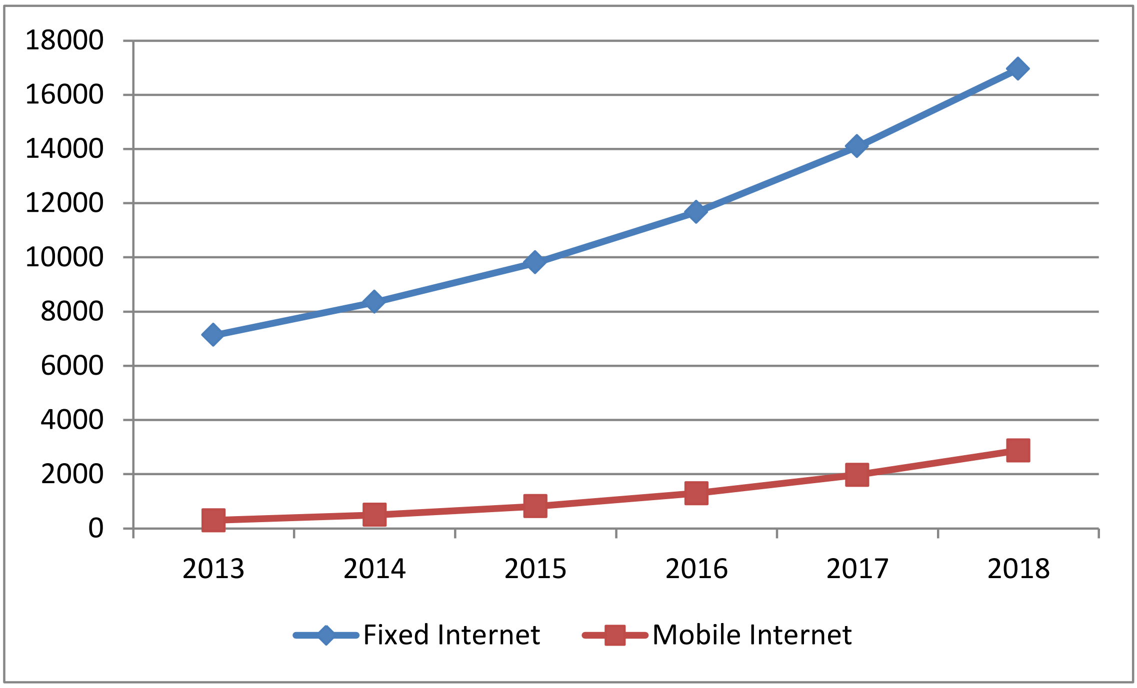


Source: Cisco (2014)[47]

Mobile data in particular is expected to continue to experience rapid traffic growth due to widespread adoption of smart phones and the massive roll-out of 3G and 4G networks and associated retail pricing plans; nonetheless, mobile data will remain relatively small compared to fixed for the next few years (see Figure 12).

47 Cisco (2014), The Zettabyte Era: Trends and Analysis, 10 June 2014.

Figure 12: Cisco VNI forecast of fixed plus mobile Internet traffic in Petabytes per month in Europe (2013-2018)

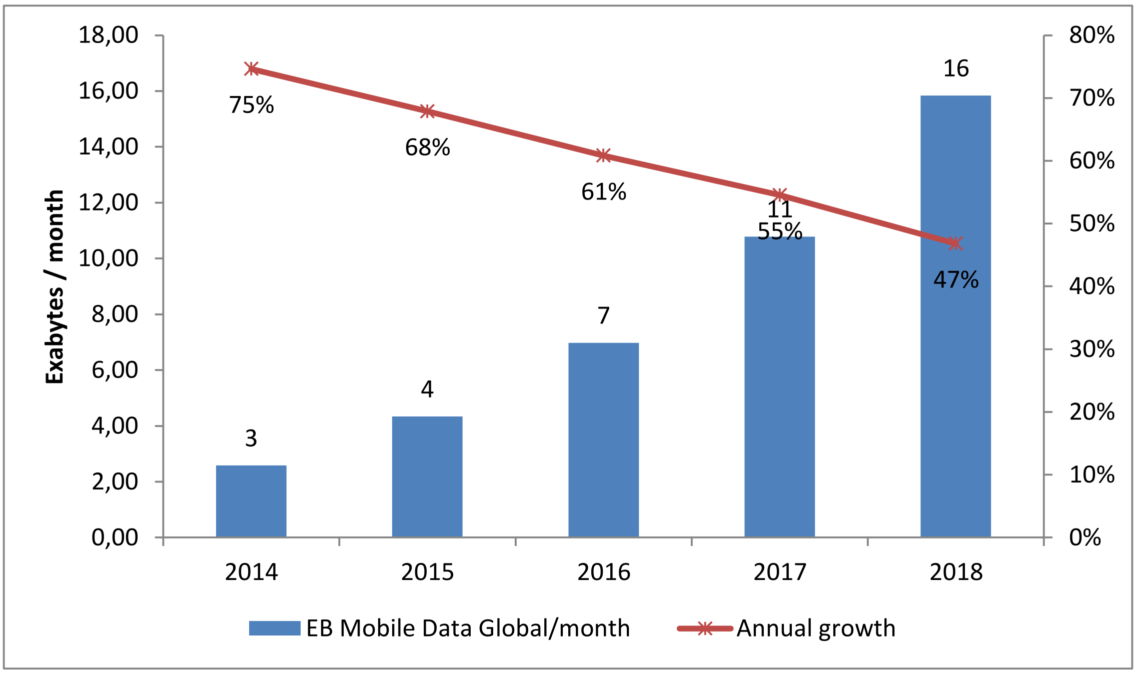


Source: Cisco VNI online database (2014),[48] WIK calculations

Mobile traffic is expected to grow year over year; however, as with fixed Internet and managed IP traffic, the percentage rate of annual growth is expected to decline over time (see Figure 13). Global mobile data traffic is expected to grow from a volume of 2.6 Exabytes per month in 2014 to a volume of 15.8 Exabytes per month in 2018; however, the annual rate of growth of mobile IP traffic year over year is expected to decline to slightly from 75% in 2014 to just 47% in 2018. These rates of growth (even though quite healthy) are far below those of Cisco VNI forecasts of just a few years ago.

48 See http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html#~overview. These data represent the aggregated traffic of Western Europe, Central Europe, and Eastern Europe. Managed IP traffic is not included.

Figure 13: Cisco VNI forecast of mobile Internet traffic in Exabytes per month and associated growth rates (2014-2018)



Source: Cisco VNI online database (2014),[49] WIK calculations

In sum, Internet traffic is growing rapidly in absolute terms over both fixed and mobile networks, but by all estimates the rate of growth is declining over time.

3.6 Trends in the number of subscribers

Key Findings

The number of fixed broadband subscribers continues to increase, but the percentage rate of increase is declining over time. The number of fixed broadband subscribers is growing only slowly in Europe at present.

The number of users of mobile data is increasing rapidly.

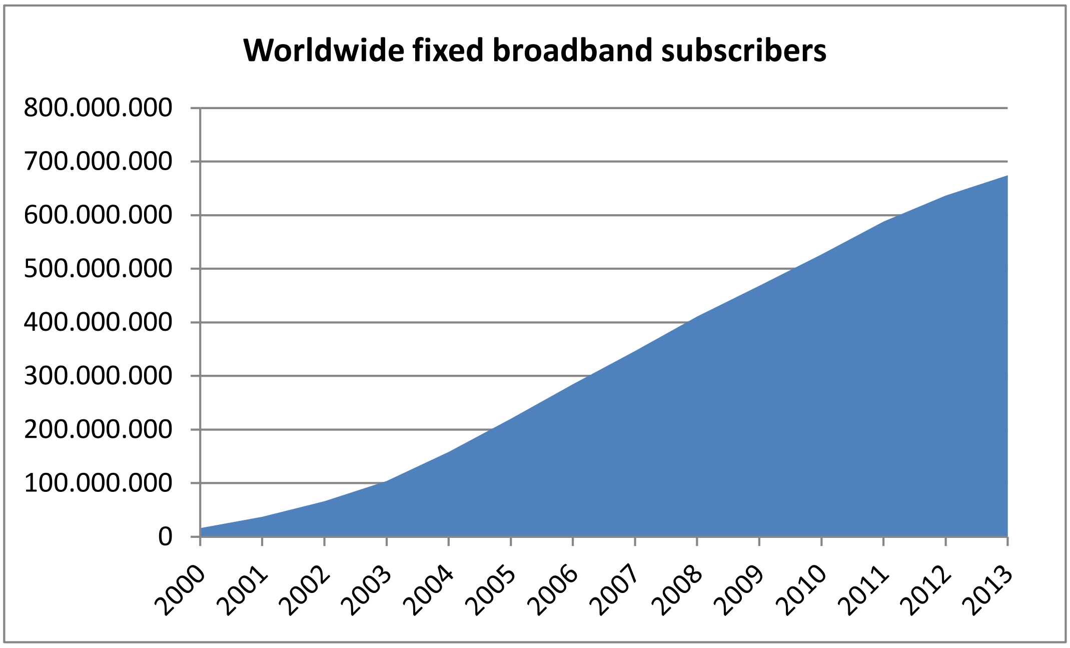
The increase in the number of fixed and mobile subscribers plays a significant role in the overall global increase in Internet traffic.

49 See http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html#~overview.

In the recent past, the growth in traffic has been driven not only (1) by an increase in the number of megabytes transmitted per subscriber, but also (2) by an increase in the number of subscribers.[50] For purposes of this analysis, it is important to distinguish between the two, because in general each subscriber added also represents added revenue. The two drivers of growth thus have significantly different implications for the profitability of network operators.

ITU data show a substantial growth in the worldwide number of fixed broadband subscribers over the years. The growth curve demonstrates the expected shape of the letter "s", but over a small number of years it is nearly linear.

Figure 14: Worldwide fixed broadband subscribers



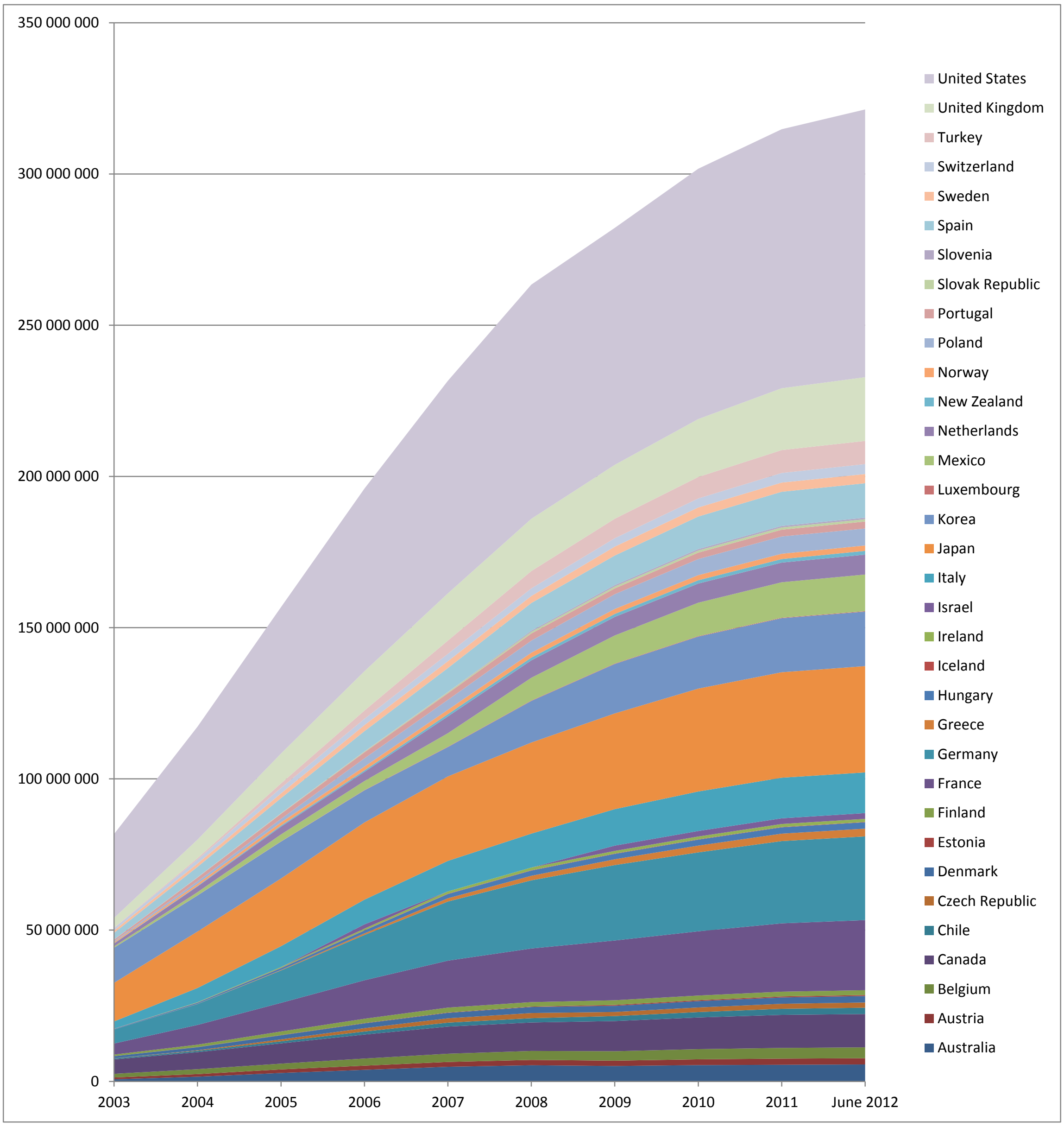
Source: ITU data, WIK calculations.[51]

50 In the interest of readability, we speak here of subscribers, but not all Internet traffic is driven by a human being sitting at a computer. Sensors and intelligent devices that communicate via IP are reflected in the various data sources on which we have relied.

51 ITU World Telecommunication / ICT Indicators database.

A review of OECD data shows that the number of subscribers has increased in all OECD countries, but there are significant differences from one OECD country to the next (see Figure 15).

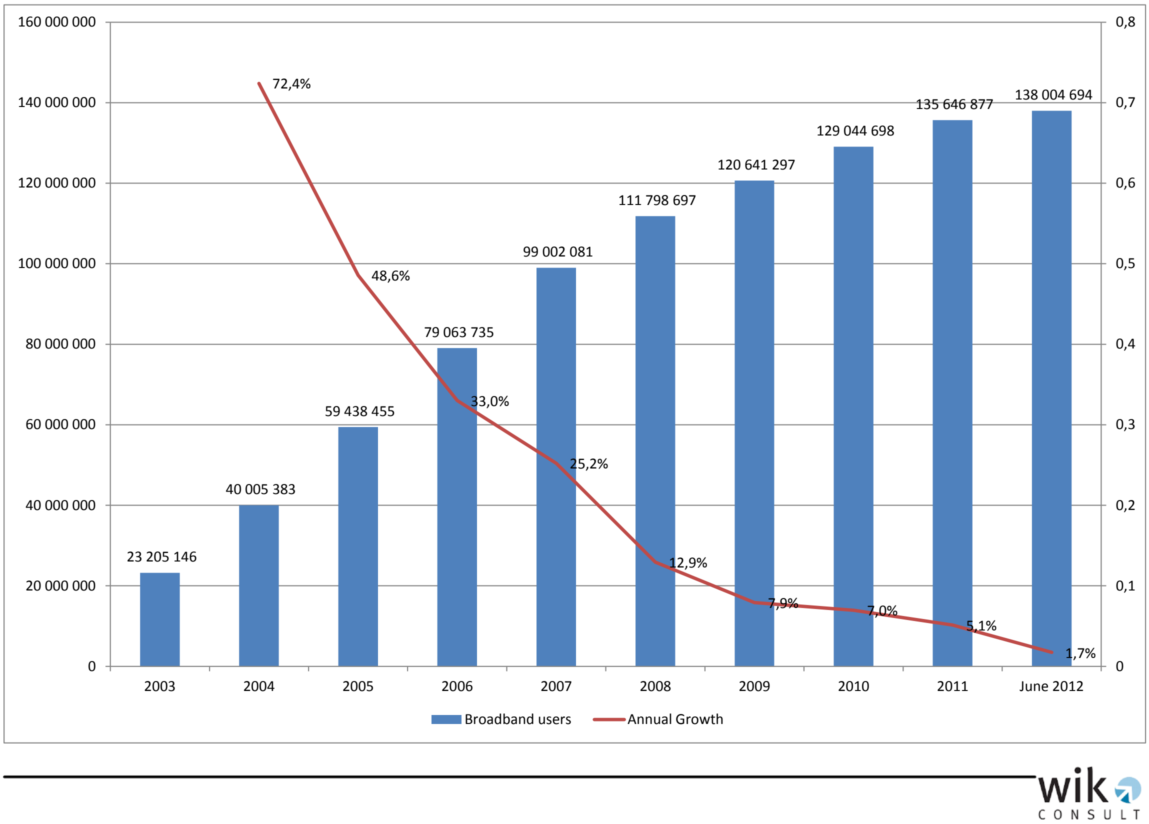
Figure 15: Fixed broadband subscriptions for OECD members



Source: OECD Communications Outlook 2013 Table 4.10, WIK calculations

In assessing solely those OECD members that are European,[52] we find once again that the absolute number of subscribers grows over the years, but the percentage growth declines over time (see Figure 16).

Figure 16: Growth in the number of fixed subscribers in Europe (2003-2012)



Source: OECD *Communications Outlook 2013* Table 4.10, WIK calculations

3.7 Trends in traffic per subscriber

The question that we are addressing is the degree to which growth in traffic implies a corresponding growth in relevant costs. As previously noted, traffic growth is driven by a combination of (1) growth in the number of subscribers and (2) growth in traffic per subscriber. It is the latter that is of interest, since growth in subscribers implies not only a growth in costs but also a growth in revenues.

We presented traffic volumes in Section 3.5, and trends in the number of subscribers in Section 3.6. Traffic per subscriber is simply the former divided by the latter.

52 Including not only EU Member States, but also EEA members (Iceland and Norway) and Switzerland.

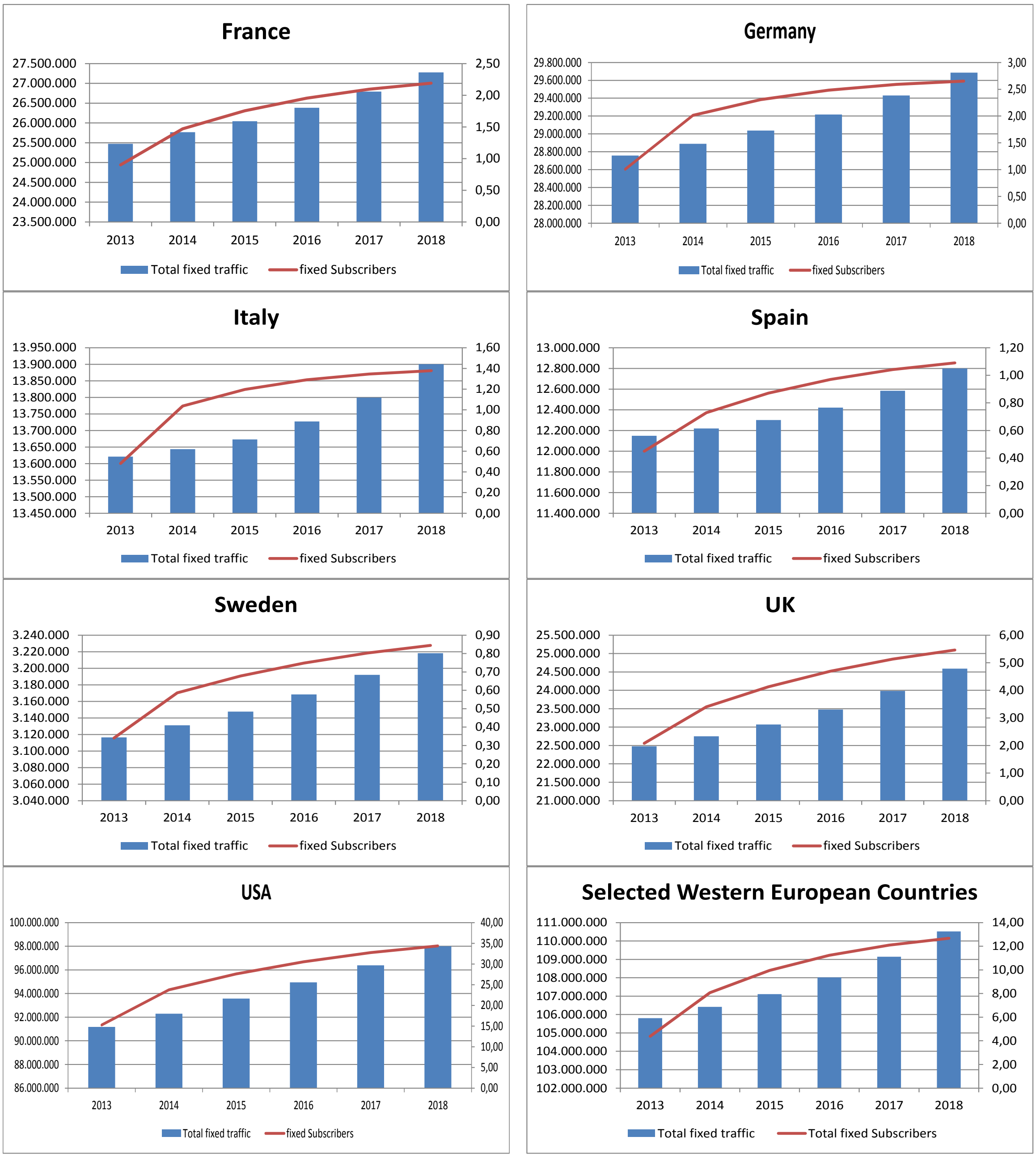
We have selected six leading European countries: France, Germany, Italy, Spain, Sweden, and the UK. We also make estimates for the USA, and for the six countries together (as a proxy for Europe as a whole).

For each of these, we have taken the OECD historical data on fixed subscribers and extrapolated it forward using a logistics curve (the typical functional form used to express take up over time of a new technology). The evolution of total traffic and total subscribers for the period for all seven countries (and the six European countries together) appears in Figure 17.

We then divided the Cisco traffic forecasts for fixed Internet traffic plus managed IP traffic for the years 2013 through 2018 by the predicted number of users in order to estimate the growth of traffic per user. The traffic per fixed subscriber, expressed in GB per month, appears in Figure 18, together with the annual rate of growth in traffic per user.

The CAGR for fixed Internet and managed IP traffic in the six European countries in aggregate for the period 2013-2018 is 16.3%; the corresponding CAGR for the United States is 16.6%.

Figure 17: Number of subscribers and projected traffic in Exabytes (2013-2018)



Source: Cisco online VNI database (2014), OECD Communications Outlook 2013, WIK calculations

Figure 18: Projected traffic per fixed subscriber in Gigabytes per month and growth rate (2013 2018)

Source: Cisco online VNI database (2014), OECD Communications Outlook 2013, WIK calculations

3.8 Trends in pricing

Key Findings

Retail revenue per subscriber per month (expressed as *average revenue per user*, or *ARPU*) for fixed broadband Internet access in Europe has slightly declined in recent years. Modest increases are visible the Netherlands, modest decreases in the UK, Germany, Spain, and Poland, and mixed movements in France. The slight downward trend in *price per user* is consistent with the slight decline in *cost per user*.

Retail prices for consumer fixed and mobile broadband services in the EU tend to move up or down in response to underlying costs, in this market as in most competitive markets. If costs for fixed broadband had increased dramatically, prices for fixed broadband would have increased dramatically, as has been the case in the mobile market.

It may be challenging to get a customer to accept a higher price for an existing service, but network operators can and do implement price increases in other ways. They may implement data caps, possibly accompanied by pricing for data in excess of the cap. They may "upsell", making it easy for the customer to acquire a faster, more expensive service.

This is now visible in the mobile marketplace, where ARPU has increased dramatically. CAGRs for mobile Internet data ARPU range from 11% to 65% over the period 2007-2012.

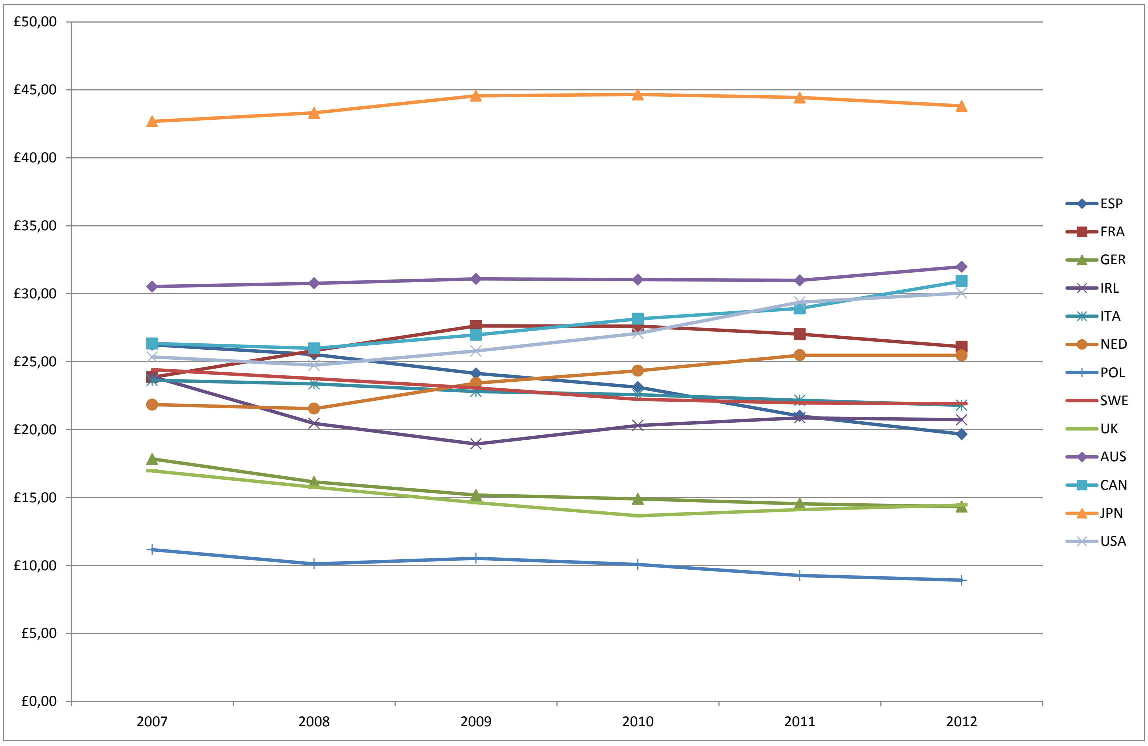
Total retail revenue has increased in rough proportion to the number of subscribers.

Relevant usage based costs are declining. Total global expenditures for Internet transit are expected to slightly decline over the period 2013-2020 (see Section Figure 8, and more generally Section 3.4.2), reflecting a large decline in unit costs that more than offsets the increase in volume. Electronic components (including DSLAMs and CMTs in the case of cable television networks) are becoming cheaper and more capable (see Section 3.4.1). Civil works and copper and fibre cabling are not enjoying comparable declines in unit cost over time. Thus, the expectation would be for only a modest decline in the price of the connection, but a rapid decline in the price per Mbps carried (both over the connection itself, and also over the backbone network that carries the traffic to destinations around the world).

Fixed broadband price and revenue trends are best seen in data collected by IDATE for Ofcom, the UK National Regulatory Authority (NRA). IDATE annually estimates total broadband revenue for various national markets, an approach that avoids the risk of being misled by for instance a single offering.[53] The monthly revenue divided by the number of lines or subscribers is referred to as the *Average Revenue Per User* (*ARPU*).

In a 2011 study,[54] we found that monthly ARPU for fixed broadband connections had been fairly stable for the five largest European markets over the period 2006-2010. France had seen some increase, the UK some decrease, but overall ARPU had been fairly stable. The same is largely true in the current data for 2007-2012, where more countries are visible. There is a gradual downward trend for the UK, Germany, Spain, and Poland, a gradual upward trend for the Netherlands, and mixed indications for France (see Figure 19). On balance, the movement in Europe is toward slightly lower ARPU; however, price movements are not dramatic.

Figure 19: Average Revenue per User (ARPU) in GBP for fixed broadband in selected countries (2007-2012)



Source: IDATE (2013),[55] WIK calculations

53 Retail prices are often compared using price baskets or databases of retail prices, but this method is notoriously risky. The price basket tells you that an offer is nominally in the market, but does not tell you whether it is used, or how much it is used, or how it is used.

54 J. Scott Marcus and Alessandro Monti (2011), “Network Operators and Content Providers: Who Bears the Cost?”, 13 September 2011, available at: http://ssrn.com/abstract=1926768.

55 As reported in Ofcom (2013), International Communications Market Report, 12 December 2013.

As previously noted, we consider this slight decline in prices not to represent a market flaw, but rather an indication that the market is functioning as it should. Costs per user in the fixed network are slightly declining; therefore prices per user (i.e. ARPU) are stable or slightly declining. The increase in traffic per user is fully offset, as we have seen, by a reduction in usage-based unit costs per user.

There is another reason why small declines are not necessarily problematic. One would expect in general that ARPU should decline somewhat as the number of subscribers increase, since new subscribers will tend to consumer less than previous subscribers. The data suggest that, however, that such an effect cannot be very strong. This downward pressure is perhaps offset by the tendency of users to upgrade the speed of the connection from time to time, usually at a slightly higher price.

Overall, the relative stability of ARPU also reinforces the notion that revenues tend to be roughly proportionate to the number of subscribers.

It should also be clear from this data that *prices move in both directions*.

The same IDATE data also show that total fixed broadband total revenues are increasing in all of the markets analysed. The increase in the number of subscribers more than compensates for any decline in ARPU. Table 1 depicts estimated total broadband revenue in billions of GBP.

Table 1: Total fixed broadband revenues in billion GBP in selected national markets (2007 and 2012)

	Revenues (GBP bn)		Revenue
	2007	2012	CAGR
ESP	2,3	2,7	2,7%
FRA	4,1	7,3	12,4%
GER	3,7	4,8	5,4%
IRL	0,2	0,3	8,2%
ITA	2,6	3,6	6,2%
NED	1,4	2,1	7,7%
POL	0,4	0,6	6,0%
SWE	0,7	0,8	1,6%
UK	3,0	3,7	4,4%
AUS	1,5	2,2	7,8%
CAN	2,7	4,2	9,4%
JPN	13,8	20,1	7,8%
USA	19,7	32,4	10,5%

Source: IDATE (2013),[56] WIK calculations

56 As reported in Ofcom (2014), International Communications Market Report, 12 December 2013.

There is a modest downward trend in broadband pricing (as expressed by ARPU) in the fixed network in some countries (not all), but there is a very strong upward trend in Internet data ARPU in the mobile network, as shown in Table 2.

Table 2: Compound Annual Growth Rates (CAGRs) for fixed and mobile subscribers in selected countries (2007-2012)

	Total revenue	Number of fixed connections	ARPU per fixed connection	Data ARPU per mobile subscriber
ESP	2,7%	7,4%	-5,6%	24,2%
FRA	12,4%	8,7%	1,8%	23,6%
GER	5,4%	7,4%	-4,3%	26,5%
IRL	8,2%	7,9%	-2,8%	
ITA	6,2%	6,3%	-1,6%	11,5%
NED	7,7%	3,4%	3,1%	41,6%
POL	6,0%	7,1%	-4,4%	21,8%
SWE	1,6%	2,4%	-2,1%	48,7%
UK	4,4%	6,6%	-3,2%	65,3%
AUS	7,8%	5,1%	0,9%	38,7%
CAN	9,4%	5,0%	3,3%	27,5%
JPN	7,8%	7,1%	0,5%	10,8%
USA	10,5%	5,5%	3,5%	32,5%

Source: IDATE (2013),[57] WIK calculations

We noted earlier that prices move in both directions, both up and down. Even in a system of nominally flat rate prices, price increases are possible in many ways.

In a prescient paper in 2001, the American mathematician Andrew Odlyzko argued that consumers generally prefer flat rate plans to usage-based, and that flat rates are likely in consequence to prevail whenever the underlying usage-based costs to the service provider are not prohibitively high (Odlyzko (2001)). Experience tends to support his prediction. A particularly dramatic example was AT&T Wireless's introduction in the United States of Digital OneRate in 1998. They offered a nationwide flat-rate mobile telephone plan, with no per-minute charges, no distance-based charges, and no domestic roaming charges. The program was hugely successful, far beyond their expectations. Digital OneRate transformed the U.S. mobile market, forcing AT&T Wireless's competitors to merge or form alliances in order to achieve nationwide coverage so as to be able to package together a competitive offering. Analogously, when America Online implemented flat rate dial-up Internet access in 1996 (a novel innovation at the time), they experienced a huge surge in subscribership.

57 As reported in Ofcom (2014), International Communications Market Report, 12 December 2013.

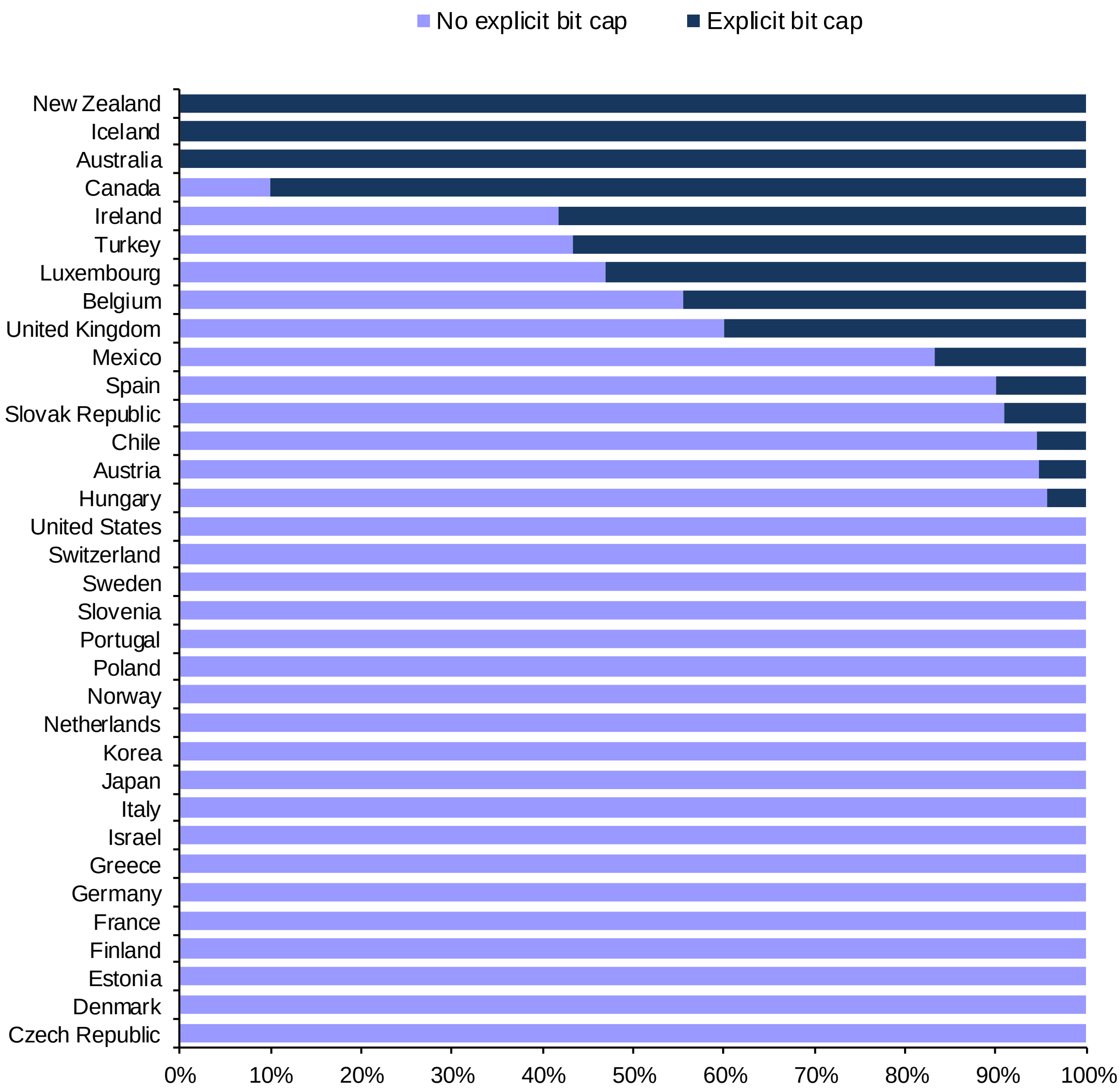
The use of flat rate plans need not mean that usage is irrelevant. In mobile arrangements, it is common to find a variant of the flat rate plan where the subscriber enjoys a true flat rate plan so long as he or she does not exceed a maximum number of minutes. These “buckets of minutes” plans are most appropriately viewed as representing banded flat rate arrangements. There are different bands, representing different numbers of total air minutes per month. So long as the consumer does not exceed the maximum number of minutes in the band, the consumer will tend to think of the plan as being purely flat rate; however, the subscriber may occasionally exceed the limit, and will be prodded by high usage-based fees to upgrade to a larger “bucket”. These plans are well evolved in the U.S., and enable mobile network operators to maintain some of the highest ARPU in the world, notwithstanding their heavy use of arrangements that are essentially flat rate.

In like manner, the imposition of usage caps and similar mechanisms could enable the imposition of price bands that respond to usage, even within an essentially flat rate structure. The prediction, based on Odlyzko (2001), is that network operators will implement these arrangements only if usage-based costs are significant.

In our 2011 study,[58] we predicted that the implementation of usage caps and other usage-based pricing mechanisms in Europe was far more likely in Europe in the mobile world than in the fixed. The across-the-board increase in mobile data ARPU (see again Table 2) likely means that this prediction has already been fulfilled. See also Figure 20 and Figure 21, which provide OECD analysis of usage caps as of September 2012. It is likely that usage caps are far more prevalent today in light of increased mobile data usage.

58 J. Scott Marcus and Alessandro Monti (2011), “Network Operators and Content Providers: Who Bears the Cost?”, 13 September 2011, available at: http://ssrn.com/abstract=1926768.

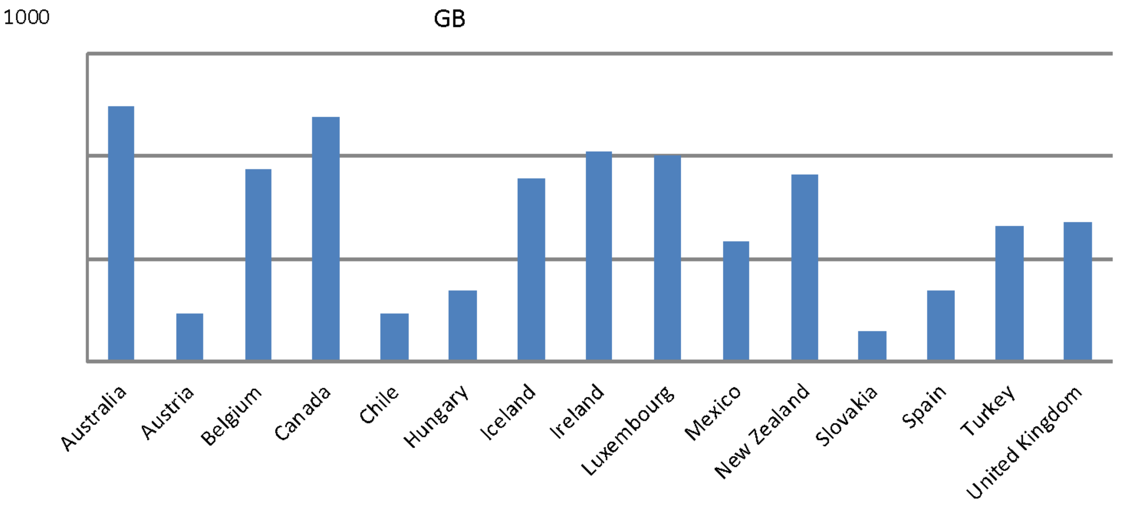
Figure 20: Prevalence of bit / data usage caps among surveyed offers (September 2012)



Source: OECD and Teligen, from OECD Communications Outlook (2013), Figure 4.19[59]

59 Also available as Figure 5f on the OECD's online broadband data portal, http://oecd.org/internet/broadband/oecdbroadbandportal.htm.

Figure 21: Average data caps (GB), logarithmic scale (September 2012)



Source: OECD and Teligen, from OECD Communications Outlook (2013), Figure 4.20[60]

3.9 Overall conclusions

Key Findings

Traffic volumes for Internet Protocol (IP) traffic are increasing, both for fixed and for mobile networks, but the percentage rate of increase is declining over time. The increase in traffic volume is partly a function of an increase in the number of subscribers, and partly a function of an increase in traffic per subscriber.

The number of fixed broadband subscribers continues to increase, as does the number of mobile users who use data services.

Unit costs for relevant network equipment are declining slightly faster than the rate of Internet traffic increase per user in the fixed network. The decline in unit costs can be viewed as an example of Moore's Law.

Retail revenue per subscriber per month (expressed as *average revenue per user*, or *ARPU*) for fixed broadband Internet access in Europe has slightly declined in recent years. Modest increases are visible the Netherlands, modest decreases in the UK, Germany, Spain, and Poland, and mixed movements in France. The slight downward trend in *price per user* is consistent with the slight decline in *cost per user*.

60 Also available as Figure 5h on the OECD's online broadband data portal, http://oecd.org/internet/broadband/oecdbroadbandportal.htm.

Retail revenue per mobile subscriber per month for Internet data (i.e. mobile data ARPU) has increased dramatically. CAGRs for mobile Internet data ARPU range from 11% to 65% over the period 2007-2012.

If costs had increased, prices would have increased. Retail prices tend to move up or down in response to underlying costs, in this market as in most healthy competitive markets. The relative stability of fixed broadband ARPU and the rapid increase in mobile data ARPU both serve to illustrate this.

If individual companies find it difficult to raise prices to levels that cover their costs due to competition, this is not a market defect. The most likely explanation is that their costs are higher than those of their competitors.

We see no evidence of market failure. Costs and revenues remain roughly in balance with one another overall.

For the fixed network, the alleged cost explosion simply does not exist. Traffic is growing, but cost is not. Usage-based costs in the fixed network represent a small fraction of total costs, and on a per-subscriber basis are declining slightly. Revenue per month is declining slightly, in parallel with costs.

In the fixed network, we see no problem with misalignment among revenues, costs, and the number of subscribers.

For the mobile network, the extremely rapid take-up of data services has induced mobile network operators to implement changes in prices or price structures, as we predicted in our 2011 report.[61] We argued that mobile operators could and would respond with effective price increases if increases in the cost of bandwidth were to become too large to ignore. The dramatic increase in mobile data ARPU, as evidenced by CAGRs ranging from 11% to 65% in eight European countries (see Table 2), bears this out. We expect once again that costs, retail prices, and the number of subscribers will continue to be in balance. Any increase in costs and prices is not necessarily a problem, in our view, but rather an indication that the market is effective.

Overall, price trends and cost trends for consumer broadband services are not an indication of market failure, but rather an indication of market success – as we have seen, consumer prices are generally moving appropriately in response to shifts in underlying cost.

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61 J. Scott Marcus and Alessandro Monti (2011), “Network Operators and Content Providers: Who Bears the Cost?”, 13 September 2011, available at: http://ssrn.com/abstract=1926768.

4 Two-sided market theory and the Internet

Key Findings

In recent years, a number of European incumbent network operators and their advisers have argued that the Internet should be viewed as a two-sided market, and that content providers should consequently be obliged to make payments to the broadband ISPs who serve end-users much as advertisers make payments to over-the-air (OTA) broadcasters. Some further argue that this is the only way to fund the deployment of high speed broadband deployment in Europe. This argument is seriously flawed.

The Internet as a whole has many characteristics that correspond to a two-sided market, but others that do not. Notably, the fact that there are multiple ISPs that cannot (and should not) coordinate their actions means there is no single two-sided platform to uniquely determine subscription and usage prices.

At the same time, the primary function of these prices in a two-sided market is to enhance societal welfare by maximising participation and usage externalities. All indications are that current arrangements in the EU are working well. There is a steady growth in the number of Internet users (see Section 3.6), and no particular indications that new, innovative services have difficulty entering the market, both of which suggest that current arrangements are already working well relative to membership externalities. Relative to usage externalities, much the same argument applies – the steady growth in Internet traffic (see Section 3.5) suggests that current arrangements are already working well. There are no indications of market failure, and the sides of the market obviously manage to come together. Thus, two-sided market theory does not provide a particular indication that any "correction" to prices in the EU is needed, nor for that matter does it indicate whether content providers should be paying *more* than they do today, versus *less*.

European policy has embraced a migration to Next Generation fibre-based Access (NGA) as part of the EU 2020 strategy. In light of the high cost of NGA deployment, some European policymakers will inevitably be under pressure to find other sources of funding. The proposal to impose an apparently unwarranted "tax" on content providers in order to cross-subsidise network operators, however, appears to us to carry greater risks, and to entail greater economic distortions, than many other potential and actual support mechanisms.

If one were going to take a two-sided market approach to NGA deployment, however, the flow of payments might well be in the *opposite direction from that which has been suggested*. If consumers are not convinced that ultra-fast connectivity is worth what it would cost, *there is a clear need for more high value high bandwidth content*.

In recent years, a number of European incumbent network operators and their advisers have argued that the Internet should be viewed as a two-sided market, and that content providers should consequently be obliged to make payments to the broadband ISPs who serve end-users much as advertisers make payments to over-the-air (OTA) broadcasters. Some further argue that this is the only way to fund the deployment of high speed broadband deployment in Europe.[62]

As we explain shortly, we think that this argument is seriously flawed.

In this section, we review the economic theory of two-sided markets as developed primarily by the researchers at the IDEI in Toulouse (Section 4.1); review a parallel IDEI analysis of Internet backbone interconnection (Section 4.2); and consider the implications going forward (Section 4.3).

4.1 Two-sided market theory

The definitive theory as regards two sided markets was for the most part developed in 2004-2005 by Rochet and Tirole, and by Armstrong.[63] In the discussion that follows, we draw primarily on Rochet and Tirole (2004).[64]

In a two sided market, a *platform* facilitates a transaction between a buyer (B) and a seller (S), as shown in Figure 22 below. The platforms adds value "…if and only if [it] can appropriately coordinate the demands of two distinct groups of customers. Beauty salons may attract both men and women, for instance, but heterosexual singles bars *must* attract both men and women – and in the right proportions. Similarly, shopping malls must attract both retailers and shoppers, auction houses need both buyers and sellers to stay in business, sellers of video games need both game players and game creators …"[65] "The interaction between a 'viewer' and an advertiser mediated by a newspaper or a TV channel occurs when the viewer reads the ad. The interaction between a caller and a receiver in a telecom network is a phone conversation and that between a website and a web user on the Internet is a data transfer."[66]

62 See for instance PAGE, Mark / ROSSI, Luca / RAND, Colin (2010): "A Viable Future Model for the Internet", A.T. KEARNEY.

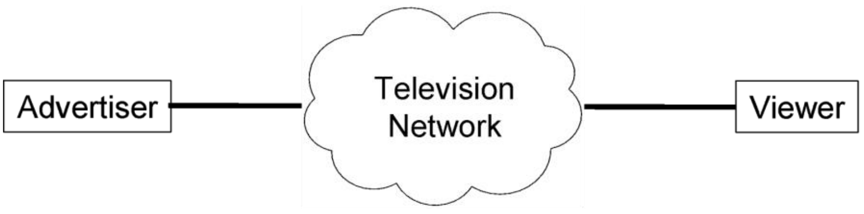
63 See Armstrong (2004) and Armstrong (2005).

64 See Rochet, Jean-Charles, and Jean Tirole, "Two-sided Markets: An Overview," mimeo, Institut d'Économie Industrielle (IDEI): Toulouse, France, March 2004.

65 See Evans, David S. and Schmalensee Richard: "The Economics of Interchange Fees and Their Regulation: An Overview", in proceedings of a conference on Interchange Fees in Credit and Debit Card Industries: What role for Public Authorities? (Federal Reserve Bank of Kansas City, Santa Fe, New Mexico, May 4-6, 2005).

66 Rochet and Tirole (2004) op. cit., page 5.

Figure 22: A two sided market



Source: Rochet and Tirole (2004).

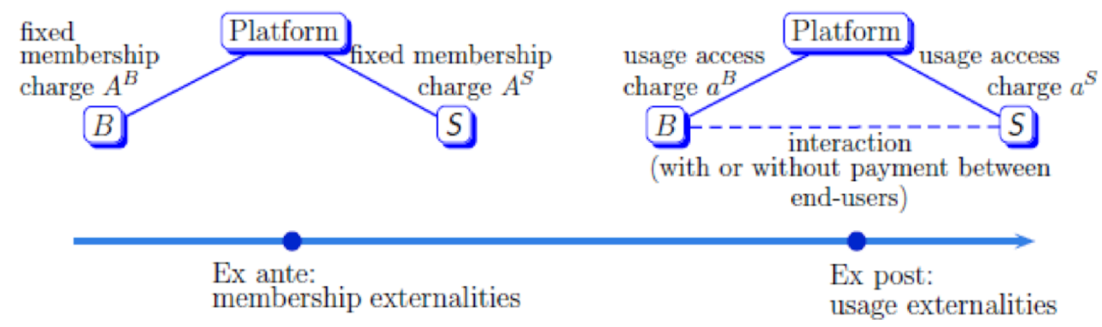
Over-the-air (OTA) broadcasters have generally found it profitable to charge the advertisers, but not the viewers. In a conventional market, it would likely be irrational for a commercial profit-oriented entity to offer a service to the general public (possibly to millions of people) at a price that is less than its short run marginal cost, but in this case that is exactly what is happening. It has long been recognised that advertisers need to reach as much of the public as possible, and that any television network that has a meaningful share of the viewers effectively has some degree of market power relative to advertisers. Conversely, consumers have many choices. In order to ensure that enough consumers are present on the broadcast platform to make the platform attractive to advertisers, OTA broadcasters find it profitable to impose charges only on advertising-funded programmers.

In practice, pricing structures tend to be far more complex, as demonstrated by relationships in the cable television sector. Low value content providers have sometimes paid cable network operators, but high value content providers (such as high valued sports) usually receive payment from cable network operators. And the level and even the direction of payments tends to depend on the scarcity of the resource provided by the platform – it is for this reason that payments from broadcasters to cable networks are shrinking, vanishing, or reversing as cable networks transition from analogue to digital, thereby alleviating any shortage of capacity.

Noting that all markets involve transactions between two or more parties, Rochet and Tirole (2004) offer the following defining characteristic: "A market is two-sided if the platform can affect the volume of transactions by charging more to one side of the market and reducing the price paid by the other side by an equal amount; in other words, the price structure matters, and platforms must design it so as to bring both sides on board."

A key contribution of Tirole and Rochet (2004) is the clear distinction between membership/subscription charges versus usage charges, and between membership/ subscription externalities versus usage externalities. S*ubscription fees* are independent of the volume of services consumed on both sides of the market, but influence the degree to which both sides of the market are present on the platform. *Usage fees* for the platform impact the willingness of both sides of the market to trade and thus inevitably have a direct influence on fees that both sides of the market pay for usage of the service.

Figure 23: Subscription and usage fees in a two-sided market



Source: Rochet and Tirole (2004)

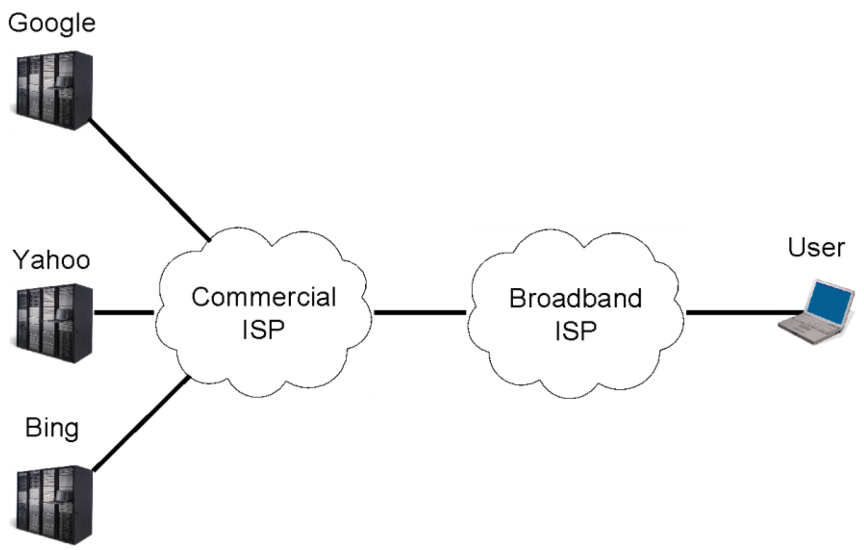
Rochet and Tirole (2004) observe that a two-sided market may have intermediaries, rather than comprising a single platform, and notes that Internet backbones are a case in point; the relevant question, however, is how one should analyse such a system. The so-called *LMRT paper* (Laffont, Marcus, Rey and Tirole (2003)) discussed in Section 4.2 addresses this point more directly.

4.2 Two-sided markets and the Internet

The LMRT paper (Laffont, Marcus, Rey and Tirole (2003)) provides a comprehensive economic assessment of Internet backbone peering. The analysis distinguishes between Internet content providers ("websites") versus Internet users ("eyeballs"), thus anticipating the later seminal Toulouse work on two-sided markets (notably the Rochet & Tirole (2004) paper mentioned in Section 4.1) but also extending it.[67] Rather than modelling a single two-sided platform, the LMRT paper modelled the interactions and especially the level of access payments between two Internet backbone ISPs, as depicted in Figure 24, with their respective end-users.

67 LMRT refers to the authors: Laffont, Marcus (the author of this report), Rey, and Tirole. As noted, there is a great deal of commonality with Rochet and Tirole (2004).

Figure 24: Application services, ISPs, and end-users in the LMRT paper



Source: WIK[68]

The LMRT paper arrived at a number of relevant results and conclusions:

- Under suitable assumptions, and in the absence of market power, price for traffic sent would reflect the sum of the on-net origination costs plus any access fee that might be charged;[69] price for traffic received would reflect on-net termination costs minus the access fee. With two part tariffs (e.g. monthly fees and usage fees), only the usage fees would reflect the access charges.
- Any profits would be competed away (assuming perfect competition, which is unlikely in the real world).
- A key finding is that, in the absence of direct payments between consumers and content providers, any access fees determine the allocation of communication costs between content providers (senders) and consumers (receivers). It also affects the level of traffic.
- The socially optimal access charge would reflect Ramsey pricing principles, taking into account not only the demand elasticities of both content providers and consumers, but also the magnitude of the externality that each exerts on the other. Increasing the consumer price would discourage some consumers, which would reduce content provider surplus. Similarly, increasing the content provider

68 J. Scott Marcus, Pieter Nooren (TNO) and Jonathan Cave (RAND), "Network Neutrality: Challenges and responses in the EU and in the U.S." available at: http://www.europarl.europa.eu/activities/committees/studies/download.do?language=en&file=36351.

69 Today, the access fee is often, but not always, zero.

price would reduce consumer surplus. The optimal trade-off thus depends on how many end users are discouraged on one side, as well as on the net surplus lost on the other side, and balances the two types of welfare losses. (In practice, these elasticities tend to be unknown and perhaps unknowable.)

- The presence of market power implies that networks are not perfectly substitutable, i.e. that quality differentiation is present. Quality of Service (QoS) is analysed in this context.
- If an ISP has market power, its ideal access charge will depend not only on elasticities of demand and network externalities, but also on the ISP's relative market power in relation to websites and consumers.

When the Internet was first privatised in 1995, most (but not all) Internet peering was free of charge. This largely remains true today, but with noteworthy exceptions.[70]

The arrangements that have existed in the world as it is (where zero access fees are common) appear to have encouraged a "virtuous cycle" where content was created that motivated ever more users to join the Internet, and that growth in users created in turn an expanding market for new content. There is no way to test the counterfactual case, but one would expect in general that lower (i.e. negative) access fees would have resulted in still more content being created (thus appealing to consumers), but at the cost of higher retail prices for consumers, thus discouraging them. Conversely, higher positive access fees would have discouraged content providers, resulting in less content being available to lure consumers to the Internet; however, prices to consumers for Internet access would have been lower, possibly attracting consumers. In each case, the relative magnitude of effects is difficult to predict.

The interest in network neutrality rules has inspired a wealth of new papers that consider whether payments between content providers and the "Broadband ISP" in Figure 24 are beneficial or harmful to societal welfare. Sharkey and Bykowsky (2014b)[71] contains a good comparative summary of many of the most relevant papers.[72] An overall conclusion is that whether a rule that prevents price or quality discrimination enhances or reduces societal welfare depends on a great many factors and assumptions, most of which were explicit or implicit in the LMRT paper.

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70 See Dennis Weller and Bill Woodcock (2012), INTERNET TRAFFIC EXCHANGE: MARKET DEVELOPMENTS AND POLICY CHALLENGES, OECD. They found that 99.5% of interconnection agreements are concluded without a written contract; however, it may be that a very small fraction of the contracts account for most of the traffic carried. Some have suggested, moreover, that paid peering arrangements have become more common over time. See FARATIN et al. (2008).

71 Mark M. Bykowsky and William W. Sharkey (2014b), 'Welfare Effects of Paid for Prioritization Services: A Matching Model with Non-Uniform Quality of Service', available on SSRN.

72 See also J. Scott Marcus (2014), "Network Neutrality Revisited: Challenges and responses in the EU and in the U.S.", forthcoming.

- Whether the Broadband ISP has market power,[73] and whether it is able to extract all the surplus from the end user consumer side of the market.[74]
- Whether the value that Application or Content Providers place on an additional subscriber is greater than the value that subscribers place on an additional Application or Content Providers.
- Whether the Broadband ISP derives more revenue from end user subscribers than from Application or Content Providers.
- The level of the elasticity of demand with respect to transmission time on the part of end user consumers and of Application or Content Providers.
- The nature and intensity of Broadband ISP competition for end user consumers, and the degree to which payments required on the part of Application or Content Providers reduces their participation in the market.

4.3 The challenge of funding Next Generation Access (NGA)

Throughout Europe, and indeed throughout the world, there is enormous interest in promoting the deployment of high speed fibre-based Next Generation Access (NGA).[75] Fibre-based NGA is widely viewed as a key enabler for overall economic progress, and a cornerstone of a knowledge-based society.

4.3.1 The cost of fibre-based NGA poses a challenge to deployment

There are profound challenges in funding the European deployment of NGA. Deployment is expensive (see Table 3). Various studies suggest that no European Member State is likely to achieve full coverage of the national territory without some form of public policy support.

Estimates of the cost to achieve full coverage of the EU-27 at 30 Mbps by 2020, together with 50% of broadband customers actually served at 100 Mbps, can vary greatly, but even the most modest estimates suggest a gap of some € 82 billion[76] solely

73 Mark M. Bykowsky and William W. Sharkey (2014b), 'Net Neutrality and Market Power: Economic Welfare with Uniform Quality of Service', available on SSRN.

74 Jay Pil Choi, Doh-Shin Jeon, and Byung-Cheol Kim (2014), 'Net Neutrality, Business Models, and Internet Interconnection', available at http://www.econ.gatech.edu/files/papers/AEJMicro-2013-0162-Revision.pdf.

75 Notably, the EU 2020 strategy seeks to achieve availability of 30 Mbps broadband to all Europeans by 2020, with half of all broadband consumers served at speeds of 100 Mbps or more. See European Commission (2010): EUROPE 2020 - A strategy for smart, sustainable and inclusive growth, COM (2010) 2020.

76 Point Topic (2013), Europe's broadband investment needs: Quantifying the investment needed to deliver superfast broadband to Europe.

to achieve 30 Mbps coverage for all residents of all European Union Member States.[77] A recent study[78] shows the high cost, but also the wide spread among existing estimates, in achieving this objective for Italy alone (see Table 3).

Table 3: CAPEX required to achieve 30 Mbps coverage in Italy (2014)

Source of estimate	Coverage	CAPEX needed (€ billion)
Infratel	95% of population	€ 4.2
Caio et al. (2014)	100% of households	€ 9.2
Point Topic (2013)	100% of households	€ 12.2
EIB (2011)	100% of households	€ 10.2 to € 14.0

Source: Francesco Caio, J. Scott Marcus and Gérard Pogorel (2014), Achieving the Objectives of the Digital Agenda for Europe (DAE) in Italy: Prospects and Challenges

This creates an understandable impetus to look for other funding vehicles. A number of approaches have been considered in the EU in recent years. One approach that has been considered in some detail would reflect some level of subsidy on the part of Member State governments. The willingness of private parties to make these investments based solely on commercial considerations is in doubt, which seems to suggest the need for public subsidies; however, a subsidy programme, particularly one of this size, naturally raises a range of concerns, not only as to where the money is to come from, but also about the degree to which it might distort markets.[79]

4.3.2 Challenges on the demand side

These high deployment costs confront enormous obstacles on the demand side. Consumers have only limited interest in NGA at present – incremental *willingness to pay* (*WTP*) for ultra-fast broadband is at most only about € 5 per month, which is nowhere near enough to fund the initial investment needed in most parts of the national territory.[80] If WTP were higher, it would be possible to cover more of the national territory without subsidy. This may eventually be the case, but it is not yet the case in Europe today.

77 This is the second of the three broadband objectives that are part of the Digital Agenda for Europe (DAE). The DAE specifies industrial policy objectives at European level. The DAE also calls for 50% adoption of 100 Mbps service.

78 Francesco Caio, J. Scott Marcus and Gérard Pogorel (2014), 'Achieving the Objectives of the Digital Agenda for Europe (DAE) in Italy: Prospects and Challenges', a study for Prime Minister Letta.

79 In Member States where cable television plays a significant role, it is also necessary to ask whether subsidies to fibre-optic based telecommunications might not inherently represent a market distortion.

80 See COSTA ELIAS (Caisse des Dépôts), "When and why PPPs are an option for NGA?", EPEC workshop, 15 February 2011, at: http://www.eib.org/epec/resources/presentations/nga-roundtable-costa-elias.pdf.

Policy in Europe and in much of the world has tended to focus primarily on supply side interventions in order to close the gap. There is strong reason to question whether a supply side only approach is effective – it likely constitutes “pushing on a rope”. Complementary measures on the demand side are in order.

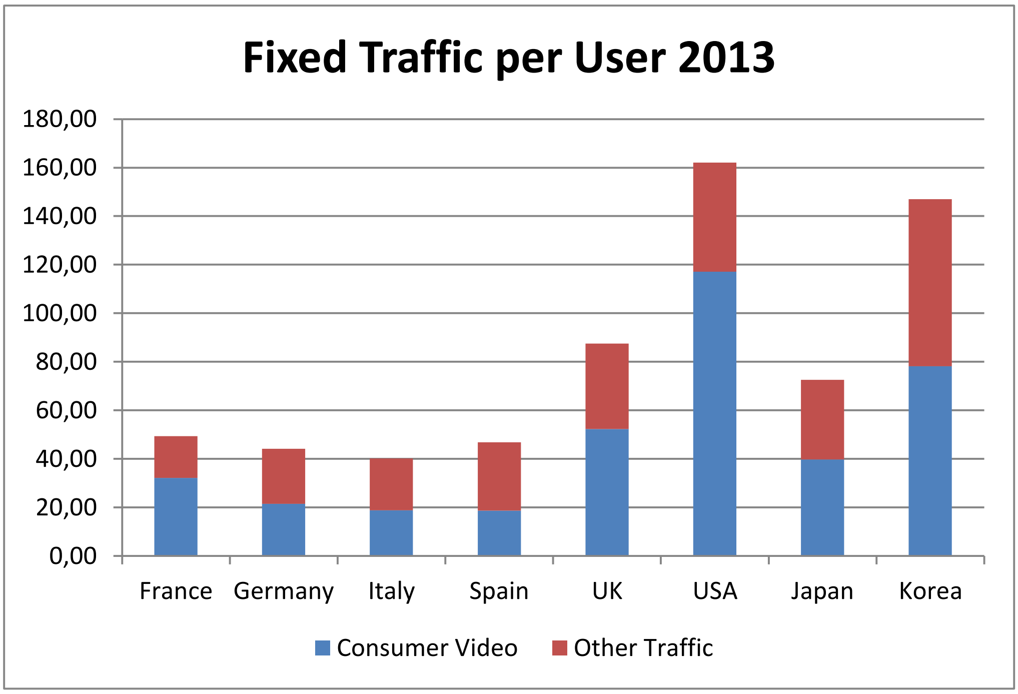
Our recent study of broadband deployment and adoption on behalf of the Prime Minister Letta of Italy[81] found, for instance, severe gaps on the demand side, including a declining number of fixed lines, penetration of fixed broadband that is stalled at current levels, limited consumption of audio-visual content, an aging population, and too few personal computers.

Low consumption of audio-visual content was a particular concern. “Some interviews suggest that the availability of content in the Italian language to Over-the-Top providers (OTTs) is limited, thus posing an impediment to consumer demand. For many aspects of online video, revenues in Italy are negligible, while other Member States steam ahead. … Based on Cisco VNI traffic estimates and projections, it is clear that bandwidth consumption in Italy is lower in Italy than in other ‘big five’ EU Member States, and also lower than many global competitors including Japan, South Korea, and the United States. Consumer video bandwidth consumption (the light blue portion of each column in Figure 25) clearly makes a large contribution to this deficit.’[82]

81 Francesco Caio, J. Scott Marcus and Gérard Pogorel (2014), Achieving the Objectives of the Digital Agenda for Europe (DAE) in Italy: Prospects and Challenges.

82 Ibid.

Figure 25: Bandwidth consumption per household, Italy and selected countries (2012)



Source: Cisco VNI online data (2013), WIK calculations

The study goes on to note pointedly "… that DAE Objectives are not likely to be achieved in Italy, nor to bring the desired benefits even if they were achieved, unless complementary initiatives to increase Italian consumption of online linear, on-demand and interactive media are also implemented and effective."

As we noted in a recent study for the European Parliament,[83] "[t]he relationship between promotion of supply versus demand was explored in two studies by largely the same group of authors in 2011: Belloc et al. (2011),[84] and Parcu et al. (2011)[85] … Belloc et al. (2011) used panel data regression and quantile regression analysis techniques to study the effects of public policy measures on broadband adoption in 30 OECD economies. … The two studies arrived at largely the same findings. *Demand stimulation can have a measurable and statistically significant effect on broadband adoption.* [emphasis added] Not only the magnitude of demand stimulation is important, but also the timing. Sufficient supply must already be present."

83 J. Scott Marcus, Ilsa Godlovitch, Pieter Nooren, Dieter Eilxmann, and Bram van den Ende (2013): "Entertainment x.0 to boost Broadband Deployment", study on behalf of the European Parliament's Committee on Industry, Research and Energy; October 2013.

84 Belloc, F., Nicita, A. and M. A. Rossi (2011), The Nature, Timing and Impact of Broadband Policies: a Panel Analysis of 30 OECD Countries, University of Siena.

85 Parcu, P. L. et al. (2011), Study on Broadband Diffusion: Drivers and Policies. Study by the Florence School of Regulation on behalf of the Independent Regulators Group.

4.3.3 Cross subsidies between market sectors

In recent years, European incumbents or experts working on their behalf have sometimes argued that content providers (or their ISPs) should somehow be required to close the NGA funding gap by contributing to the build-out of NGA infrastructure.[86] That would represent *a cross-subsidy from one industry sector to another*. Leaving aside from the moment the question of whether such a cross-subsidy would be justified or fair, one must ask whether it would be *effective*, and whether it would be *coherent* (i.e. consistent with other European policy goals).

A serious concern with any such proposal is that it carries with it the risk of distorting competition. This is especially true of possible charges to ISPs who serve content providers, inasmuch as there is an enormous mismatch between their revenues and the sums that would actually be required. As we have seen in Section 3.4.2, the actual global marketplace for Internet transit is credibly estimated to have been some $ 2.1 billion (or about € 1.6 billion) for all of 2013.[87] As we have seen in Section 4.3.1, even the most modest estimate of the cost of achieving only the second of the three Digital Agenda for Europe objectives comes to some € 82 billion. Any subsidy large enough to be useful in funding broadband deployment for Europe alone would have a huge impact on the quite modest revenues associated with global transit, and would also be totally disproportionate (leaving aside questions of equity) to the sums that European network operators pay for transit.

There are obvious additional problems with these proposals: the risk of an uneven playing field, the risk of unwarranted selective advantages to some firms, and equally unwarranted selective disadvantages to others, and the risk of negative impact on overall European competitiveness. There is also the certainty that consumers would ultimately be faced with higher prices, since the charges would necessarily be passed through (see Section 4.2).

4.4 Conclusions

The Internet as a whole has many characteristics that correspond to a two-sided market, but others that do not. Notably, the fact that there are multiple ISPs that cannot (and should not) coordinate their actions means there is no single two-sided platform to uniquely determine subscription and usage prices.

These difficulties in coordination can be substantial. The technical capability to implement Quality-of-Service-aware peering has existed since the late nineties, and many or most ISPs believe that doing so on a broad scale would be profitable;

86 See, for instance, PAGE, Mark / ROSSI, Luca / RAND, Colin (2010).

87 This is a worldwide estimate – the total just for Europe must be substantially less. There is, to be sure, also self-supply within the network operators (which the network operators presumably do not propose to tax), as well as settlement-free peering.

nonetheless, it has not come into existence, largely due to the *transaction costs* of coordinating among a large number of independent ISPs.[88]

The primary function of prices in a two-sided market is to maximize participation and usage externalities. All indications are that current arrangements are working well in the Internet today. There is a steady growth in the number of Internet users (see Section 3.6), and no particular indications that new, innovative services have difficulty entering the market, both of which suggest that current arrangements are already working well relative to membership externalities. Relative to usage externalities, much the same argument applies – the steady growth in Internet traffic (see Section 3.5) suggests that current arrangements are already working well. There are no particular indications of market failure, and the sides of the market obviously manage to come together (see Chapter 3 overall). Thus, two-sided market theory does not provide a particular indication that any “correction” to prices is needed, nor for that matter does it indicate whether content providers should be paying *more* than they do today, versus *less*.

European policy has embraced a migration to Next Generation fibre-based Access (NGA) as part of the EU 2020 strategy. As noted in Section 4.3.1, there is a significant challenge in deploying ultra-fast fibre-based NGA. Consumers are not yet willing to pay as large as premium as seems to be needed to achieve widespread deployment. Some have argued that a two-sided market transfer payment from content providers is needed in order to subsidise consumer prices and achieve widespread deployment.

As previously noted, we think that a two-sided market approach to the Internet would be highly problematic due to the lack of an integrated platform. Moreover, we do not think that it is necessary. If one were going to take a two-sided market approach to NGA deployment, however, *the most appropriate flow of payments might just as well be in the opposite direction* from that which has been suggested.[89] If consumers are not convinced that ultra-fast connectivity is worth what it would cost, *there is a need for more high value high bandwidth content* (see Section 4.3.2).

We do not seriously propose pumping money into the content provider segment – we think that doing so would cause economic distortions, and would be nearly as ill-advised as pumping money out of the sector. Moreover, we think that the content providers are collectively able to deliver the needed content and applications over time without subsidy, as long as no unwarranted impediments are placed in their way.

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88 See for instance MARCUS et al. (2011), MARCUS (2006), and MARCUS (2004).
89 In, for example, PAGE, Mark / ROSSI, Luca / RAND, Colin (2010).

5 Findings and conclusions

Key Findings

We see no evidence of market failure between consumers, ISPs, and content providers in Europe.

- Content providers make substantial payments for their network connectivity, either through payments to a transit provider or through investment in infrastructure. There is no free riding problem.
- The rapid increase in Internet traffic does not equate to an equivalent increase in cost. Costs, prices, and the number of subscribers appear to be growing in balance with one another overall. We see no indication of market failure.
- Since the diagnosis that some have put forward is wrong-headed, the cure that they have proposed is equally wrong-headed.

In this closing chapter, we present our key findings, our recommendations to network operators, and our recommendations to policymakers.

5.1 Key findings

Having considered the available data carefully, we believe that the premises of the "exploding traffic" argument are largely misleading if not outright incorrect, and that the conclusions are consequently dubious.

- Internet traffic growth is healthy, but by no means exploding. Even though traffic is growing, the rate of year over year growth in fixed and mobile Internet traffic, expressed in percentage terms, is declining over time (see Section 3.5).
- Internet traffic growth is driven by both (1) an increased number of users, and (2) increased traffic per user. The former is generally unproblematic, since each new user also represents a new revenue stream.
- The increased *traffic* per user does not necessarily result in significant increased *cost* per user. In the fixed network, the usage-based cost per user appears to be slightly declining over time, despite the growth in traffic per user.
- In both fixed and mobile networks, prices seem to respond to changes in underlying costs, as they should in competitive markets.

- o In the fixed network, the positive unit cost impact of Moore's Law price/performance improvements is now marginally greater than the negative unit cost impact of traffic growth per user.[90]
- o In the fixed network, broadband prices appear to be declining slightly (see Section 3.8).
- o In the mobile network, the positive unit cost impact of Moore's Law price/performance improvements appears to be significantly smaller than the negative unit cost impact of traffic growth per user.
- o In the mobile network, effective prices have increased substantially (see Section 3.8).
- o In both fixed and mobile markets, costs and prices are moving in the same direction, and at roughly similar rates. This is not an indication of market failure;[91] on the contrary, it is strongly suggestive of competitive markets that are generally functioning as they should.

- Two-sided market theory tells us that it might be rational to have a market outcome other than that which we could expect in a conventional one-sided market, but it does not necessarily imply payments from content providers to network operators, as has sometimes been claimed; in fact, both the optimal direction and magnitude of payments depend on many variables (see Section 4.1).
- In particular, claims that two-sided market subsidies from end-users to network operators are appropriate in Europe in order to achieve higher rates of broadband deployment and adoption are dubious. To the extent that low consumer Willingness-to-Pay (WTP) for broadband is a root cause of slow deployment and adoption of fast broadband in Europe, as appears to be the case,[92] one could just as well argue that payments should flow in the opposite direction, in order to stimulate consumption and to encourage the creation of compelling content. Without a far deeper understanding of these dynamics than we have today, the answer is indeterminate.

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90 In a previous study in 2011, we found these effects to be in rough balance in the fixed network. Meanwhile, the rate of traffic growth year over year continues to decline, while Moore's Law improvements remain fairly steady year over year. Today, the combined effects appear to represent a slight decline in unit costs per user, despite the continued growth in traffic per user, and we expect the rate of decline in unit costs in both fixed and mobile networks to increase over time.

91 The claim that is sometimes made that consumer broadband prices are unable to adjust to market changes because they tend to be flat rate is particularly dubious. Flat rate prices can and do increase in many different ways, as is evidenced for instance by the near-disappearance in recent years of "all you can eat" flat rate plans for mobile broadband in the United States.

92 Our 2013 study of Entertainment and Broadband for the European Parliament, and our 2014 study of broadband for Italian Prime Minister Letta reinforce this point. See Francesco Caio, J. Scott Marcus and Gérard Pogorel (2014), Achieving the Objectives of the Digital Agenda for Europe (DAE) in Italy: Prospects and Challenges; and J. Scott Marcus, Ilsa Godlovitch, Pieter Nooren, Dieter Eilxmann and Bram van den Ende (2013): "Entertainment x.0 to boost Broadband Deployment", study on behalf of the European Parliament's Committee on Industry, Research and Energy; October 2013, available at: http://www.europarl.europa.eu/committees/en/imco/studies.html#menuzone.

We do *not* dispute the frequently made claim that the revenues, profits, and stock market valuations of many European incumbent network operators (not all) are in decline;[93] however, our belief is that, if traffic were not growing, the revenues of these network operators would be declining even faster than is the case. The tendency of consumers to upgrade to faster fixed broadband access (at a higher price), for instance, tends to offset the slight decline in like-for-like fixed broadband unit price over time.

In sum, we feel that current data demonstrate that traffic growth is not a root cause of the challenges that network operators face; rather, it is a factor that ameliorates the other downward pressures on revenue to which they are subject.

5.2 Recommendations to incumbent network operators

This report is largely a response to complaints over the years by a number of large incumbent network operators that they are unable to set prices at levels that recover their costs due to exploding usage-based costs and retail competition.[94]

In Shakespeare's Julius Caesar, we learn that "… the fault, dear Brutus, is not in our stars, but in ourselves."[95] As we have seen, costs are by no means exploding, and the costs that are alleged to be increasing would in any case be quite small compared to the overall costs of the business. Moreover, if costs were truly increasing for all market players, the network operators in question would have no difficulty in raising their prices. *If prices are constrained by competition to levels that are insufficient to cover the costs of some network operators, it can only mean that the costs of those network operators are high in comparison to those of their competitors.*

The firms that have raised this issue have substantial scale economies in comparison with their competitors, and substantial brand recognition that should enable them to command at least a modest price premium.

Network operators can also (1) re-examine their respective cost structures, and (2) reconsider their retail pricing arrangements.

93 See J. Scott Marcus, Ilsa Godlovitch, Pieter Nooren, Dieter Eilxmann, and Bram van den Ende (2013): "Entertainment x.0 to boost Broadband Deployment", study on behalf of the European Parliament's Committee on Industry, Research and Energy; October 2013, op. cit.

94 See for instance PAGE, Mark / ROSSI, Luca / RAND, Colin (2010): "Those who have to build and operate the networks required to carry these traffic volumes earn almost no revenue from [content providers] and are often locked into flat rate price schemes with the [consumers], continually decreasing because of retail competition." For a more recent expression of similar concerns, see heise online (2014), "Deutsche Telekom: 'Netzneutralität ist in Wahrheit die Privilegierung großer US-Internetkonzerne'",17 September 2014, at: http://www.heise.de/netze/meldung/Deutsche-Telekom-Netzneutralitaet-ist-in-Wahrheit-die-Privilegierung-grosser-US-Internetkonzerne-2392253.html.

95 Act I, scene 2.

5.3 Recommendations to policymakers and regulators

Our key recommendation to regulators and other policymakers in Europe is that it is best to rely on market forces. In regard to peering payments, there is no market failure to “correct”.

References

ADHIKARI, VIJAY KUMAR; Yang Guo, Fang Hao, Matteo Varvello, Volker Hilt, Moritz Steiner and Zhi-Li Zhang (2012): 'Unreeling Netflix: Understanding and Improving Multi-CDN Movie Delivery'.

ANALYSYS (2006): "Prospects for the Evolution of 3G and 4G", Research Report, http://www.analysysmason.com/Research/Content/Reports/Prospects-for-the-evolution-of-3G-and-4G/.

ARMSTRONG, MARK (2004): "Competition In Two-Sided Markets," Mimeo, University College London.

ARMSTRONG, MARK (2005): "Two-Sided Markets: Economic Theory And Policy Implications." Mimeo, University College London.

BCG (2013), "Reforming Europe's Telecoms Regulation to Enable the Digital Single Market", 11 July 2013.

BNETZA (2009): Beschluss in dem Verwaltungsverfahren BK 3c-09-005/E20.01.09, 31 March 2011.

BNETZA (2013), Beschluss in dem Verwaltungsverfahren BK 3C-13/002/E19.02.2013, 26 June 2013.

BOOZ&CO. (2009): "LTE: Delivering the Future of Wireless", White Paper, www.booz.com/media/uploads/LTE_Delivering_Future_of_Wireless.pdf.

BURGAN, Jeffrey (2014), "Behind the scenes with Google Fiber: Working with content providers to minimize buffering", 21 May 2014, at http://googlefiberblog.blogspot.de/2014/05/minimizing-buffering.html .

CAIO, Francesco, J. Scott Marcus and Gérard Pogorel (2014), 'Achieving the Objectives of the Digital Agenda for Europe (DAE) in Italy: Prospects and Challenges', a study for Prime Minister Letta.

CAVE, Martin (2004), "Making the ladder of investment operational", available at: www.ictregulationtoolkit.org/en/Document.2916.pdf, November 2004.

CISCO (2014), The Zettabyte Era: Trends and Analysis, 10 June 2014.

CISCO (2014), "Cisco Visual Networking Index: Forecast and Methodology, 2013–2018", 10 June 2014, available at http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.pdf.

COFFMANN, K.G. / ODLYZKO, A. M. (2001): "Internet growth: Is there a "Moore's Law" for data traffic?" http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.76.2064&rep=rep1&type=pdf.

COSTA ELIAS, H. (2011): "When and why PPPs are an option for NGA?", EPEC workshop, Caisse des Dépôts, 15 February 2011, at: http://www.eib.org/epec/resources/presentations/nga-roundtable-costa-elias.pdf.

CRÉMER, Jacques/ REY, Patrick/ TIROLE, Jean (2000): "Connectivity in the Commercial Internet", in: Journal of Industrial Economics, Vol. 48, pp. 433-472.

DELL'ORO GROUP (2011): Optical Transport Report: Five Year Forecast: 2011 – 2015, Vol. 11, No. 2 O2A, Technology Segments: WDM, Multiservice Multiplexer, Optical Switch, Optical Packet, published July 2011.

DELL'ORO GROUP (2011): Routers Report: Five Year Forecast:: 2011 – 2015, Vol. 15, No. 2 R2A, Customer Segments: Enterprise Routers, Service Provider Routers, published July 2011.

EUROPEAN COMMISSION (2010): EUROPE 2020 - A strategy for smart, sustainable and inclusive growth, COM(2010) 2020.

EUROPEAN COMMISSION (2010): Commission Staff Working Document, Accompanying document to the Commission Recommendation on regulated access to Next Generation Access Networks {SEC(2010) 1037}.

EVANS, David S./ SCHMALENSEE, Richard (2005), "The Economics of Interchange Fees and Their Regulation: An Overview", in proceedings of a conference on Interchange Fees in Credit and Debit Card Industries: What role for Public Authorities? (Federal Reserve Bank of Kansas City, Santa Fe, New Mexico, May 4-6, 2005).

FARATIN, P./ CLARK, D./ BAUER, S./ LEHR, W./ and GILMORE, P., "The Growing Complexity of Internet Interconnection", Communications & Strategies, number 72, 4th quarter, 2008.

FARRELL, Joseph / SALONER, Garth (1985): "Standardization, Compatibility, and Innovation", in: the RAND Journal of Economics, Vol. 16, pp. 70-83.

GRIES, C. and I. Philbeck (2013): Marktentwicklung im Bereich Content Delivery Networks (Market developments in Content Delivery Networks), WIK-Diskussionsbeitrag No. 376, April 2013 (German only).

HEISE ONLINE (2014), "Deutsche Telekom: ‚Netzneutralität ist in Wahrheit die Privilegierung großer US-Internetkonzerne'", 17 September 2014, at: http://www.heise.de/netze/meldung/Deutsche-Telekom-Netzneutralitaet-ist-in-Wahrheit-die-Privilegierung-grosser-US-Internetkonzerne-2392253.html.

HOTELLING, Harold (1929): "Stability in Competition", The Economic Journal, March 1929, pp. 41-57.

KATZ, Michael L. / SHAPIRO, Carl (1985): "Network Externalities, Competition, and Compatibility", in: The American Economic Review, Vol. 75, pp. 424-440.

LAFFONT, Jean-Jacques/ MARCUS, J. Scott/ REY, Patrick/ TIROLE, Jean (2003): "Internet Interconnection and the Off-Net-Cost Pricing Principle", in: RAND Journal of Economics, Vol. 34, pp. 370-390.

LAFFONT, Jean-Jacques/ TIROLE, Jean (2000): Competition in Telecommunications, MIT Press, 2000.

MARCUS, J. Scott (1999): Designing Wide Area Networks and Internetworks: A Practical Guide, Addison Wesley, 1999.

MARCUS, J. Scott (2004): "Evolving Core Capabilities of the Internet", in: Journal on Telecommunications and High Technology Law, 2004, available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=921903.

MARCUS, J. Scott (2006): "Framework for Interconnection of IP-Based Networks -- Accounting Systems and Interconnection Regimes in the USA and the UK", a background paper prepared for the German Federal Network Agency's study group on a Framework for Interconnection of IP-Based Networks, 27 March 2006, available at: http://www.bundesnetzagentur.de/media/archive/6201.pdf.

MARCUS, J. Scott / NOOREN, Pieter / CAVE, Jonathan (2011), "Network Neutrality: Challenges and responses in the EU and in the U.S."

MARCUS, J. Scott, and Alessandro Monti (2011), “Network Operators and Content Providers: Who Bears the Cost?”, 13 September 2011, available at: http://ssrn.com/abstract=1926768.

MARCUS, J. Scott (2012), “Revising the ITRs: A European policy perspective”, 30 September 012. Dieter Elixmann, Kenneth R. Carter, and senior experts Scott Bradner, Klaus Hackbarth, Bruno Jullien, Gabriele Kulenkampff, Karl-Heinz Neumann, Antonio Portilla, Patrick Rey, and Ingo Vogelsang, The Future of IP Interconnection: Technical, Economic, and Public Policy Aspects, a study prepared for the European Commission, 29 January 2008, available at: http://ec.europa.eu/information_society/policy/ecomm/doc/library/ext_studies/future_ip_intercon/ip_intercon_study_final.pdf.

MARCUS, J. Scott, Dieter Elixmann, Kenneth R. Carter, and senior experts Scott Bradner, Klaus Hackbarth, Bruno Jullien, Gabriele Kulenkampff, Karl-Heinz Neumann, Antonio Portilla, Patrick Rey, and Ingo Vogelsang (2008): “The Future of IP Interconnection: Technical, Economic, and Public Policy Aspects”, a study prepared for the European Commission, 29 January 2008, available at: http://ec.europa.eu/information_society/policy/ecomm/doc/library/ext_studies/future_ip_intercon/ip_intercon_study_final.pdf.

MARCUS, J. Scott (2014), “Network Neutrality Revisited: Challenges and responses in the EU and in the U.S.”, forthcoming.

MOORE, Gordon E. (1965): “Cramming more components onto integrated circuits”, in: Electronics, Volume 38, Number 8, April 19, 1965.

NETFLIX (2012), “Announcing the Netflix Open Connect Network”, at: http://blog.netflix.com/2012/06/announcing-netflix-open-connect-network.html.

NORTON, William B. (“Dr. Peering”) (2014), “Internet Transit Tricks”, 30 April 2014, at: http://drpeering.net/AskDrPeering/blog/articles/Ask_DrPeering/Entries/2014/4/30_Internet_Transit_Tricks.html.

ODLYZKO, Andrew (2001): Internet Pricing and the History of Communications.

ODLYZKO, Andrew (2003): “Internet traffic growth: Sources and implications”, in: B. B. Dingel, W. Weiershausen, A. K. Dutta, and K.-I. Sato (eds.): “Transmission Systems and Equipment for WDM Networking II”, Proc. SPIE, vol. 5247, 2003, pp. 1-15.

OECD (2013): OECD Communications Outlook 2013, OECD Publishing.

OFCOM (2010): “International Communications Market Report 2010”, London.

OFCOM (2013), “International Communications Market Report”, 12 December 2013.

PAGE, Mark / ROSSI, Luca / RAND, Colin (2010): “A Viable Future Model for the Internet”, A.T. KEARNEY, available at: http://www.atkearney.com/index.php/Publications/a-viable-future-model-for-the-internet.html.

ROCHET, Jean-Charles/ TIROLE, Jean (2004): “Two Sided Markets: An Overview”, in: Institut d’Economie Industrielle working paper, Toulouse, 2004.

RYAN, Patrick S., Wireless Communications and Computing at a Crossroads: New Paradigms and Their Impact on Theories Governing the Public's Right to Spectrum Access. Journal on Telecommunications & High Technology Law, Vol. 3, No. 2, p. 239, 2005. Available at SSRN: http://ssrn.com/abstract=732483.

TELEFONICA (2011): “Anticipating the future to transform the present”, London 2011 Eighth Investor Conference, presentation by César Alierta, CEO Telefonica, http://www.telefonica.com/en/shareholders_investors/pdf/eighth_investor_conference_2011/london2011_Chairman.pdf.

TELEGEOGRAPHY (2014), IP Transit Forecast Service, 8 July 2014, at: http://www.telegeography.com/research-services/ip-transit-forecast-service/.

TELEGEOGRAPHY (2014), IP Transit Revenues, Volumes Dependent on Peering Trends, 8 July 2014, at: http://www.telegeography.com/press/marketing-emails/2014/07/08/ip-transit-revenues-volumes-dependent-on-peering-trends/index.html.

WIK-Consult (2011): HOERNIG Steffen/ JAY, Stephan/ NEU, Werner/ NEUMANN, Karl-Heinz/ PLÜCKEBAUM, Thomas/ VOGELSANG Ingo, “Wholesale pricing, NGA take-up and competition”, 7 April 2011.