Nesta...

Exploring the costs and benefits of FTTH in the UK

Robert Kenny

March 2015

CONTENTS

Disclaimer

The opinions offered in this report are purely those of the author. They do not necessarily represent the views of Nesta, nor do they represent a corporate opinion of Communications Chambers.

1. EXECUTIVE SUMMARY

As a result of both purely commercial roll-outs and government intervention, by 2015 95 per cent of the UK will have access to 'fibre to the cabinet' (FTTC) broadband, providing average speed of 42 Mbp.[1] Virgin's cable network offers even higher speeds to 50 per cent of the country today, and this is set to increase to two-thirds.[2]

However, a number of countries, particularly in East Asia, have built out 'fibre to the home' (FTTH) networks which can deliver speeds of 1 Gbps or more. There are now approximately 130 million FTTH connections worldwide.[3] Some argue that the UK government should intervene to encourage nationwide FTTH here.

One challenge in making this case is that, to date, there is little evidence on the benefits of FTTH over FTTC, and in particular of the public benefits which might justify market intervention. This may conceivably be because it is too early for such benefits to have materialised. But the result is that the case for public investment in FTTH has to be on more speculative grounds – for example, based on the possibility of a new killer application requiring speeds only FTTH provides (one version of the 'future proof' argument), or on non-economic grounds altogether.

This is doubly so since all three published forecasts of UK bandwidth demands we discuss in this report suggest that FTTC will provide ample bandwidth for many years to come. Some non-UK forecasts anticipate demand for higher speeds, but still well within the capability of G.fast (the next generation of copper technology, which BT currently expects to deploy starting in 2016/17),[4] suggesting that FTTH is not essential even to meet these forecasts.

The justification for investment in FTTH needs to be strong, since it is an expensive upgrade. Based on UK and international cost studies, the cost of a UK nationwide roll-out might be approximately £25 billion (though this could be reduced appreciably if a narrower coverage target was used). Such an investment in nationwide roll-out would be very difficult to justify commercially, since there is little evidence that consumers are willing to pay a premium for the extra speed FTTH brings. Consequently, even if the government were to just provide 'gap' financing, it might need to cover a substantial portion of this cost.

It is important to note that decisions about broadband infrastructure are not 'for the ages' – rather they sit in a dynamic environment with irreversible investments and great uncertainties about new access technologies and new applications. This suggests that the optimal 'future proof' strategy may actually be one of strong 'watching brief', to monitor for developing opportunities.

Thus policymakers need to consider:

- Research into the usage patterns of households moving to higher speed connections, to understand if this results in changed behaviour and in particular increased usage of applications with positive externalities.
- Investigation of the applications in use in countries with widespread FTTH, to see if that investment has paid national dividends.

- Demonstrators, perhaps focused on areas of the UK which already have material FTTH or creative and digital clusters where businesses are arguably best placed to exploit high speeds, to see if there is the opportunity for business and civic applications built on this infrastructure.
- One or more national laboratories, similar to Australia's Institute for a Broadband Enabled Society, focused on socially valuable applications of a higher speed internet which might not be purely commercially justifiable.

2. INTRODUCTION

Since the advent of dial-up there have been numerous generations of internet access technologies. These have brought faster speeds as well as other benefits such as greater reliability and lower latency.

FIGURE 1: SELECT BROADBAND TECHNOLOGIES[5]

Type	Network	Technical Status	Typical speed
Dial-up	Copper	Obsolete	56 Kbps
ADSL 2+	Copper	Live	Up to 20 Mbps
FTTC	Fibre + Copper	Live	Up to 80 Mbps
HFC	Fibre + Cable	Live	150 Mbps
G.fast	Fibre + Copper	Field trials	700 Mbps
XG.fast	Fibre + Copper	Lab trials	1 Gbps
FTTH	Fibre	Live	1 Gbps

Most broadband users around the world are on connections that make at least some use of the historic copper networks (both telephone and cable TV). Technologies such as ADSL (asymmetric digital subscriber line), FTTC and HFC (hybrid fibre coax) all rely in whole or in part on existing networks.

In the UK BT has been investing £2.5 billion in FTTC.[6] In addition, £1.2 billion of government funds have been provided to support roll-out in areas where it would not otherwise be commercially viable.[7] As a result, FTTC coverage now reaches 21 milion premises.[8] (A further £500 million of government funding is pending to increase coverage to 95 per cent of homes).

Even in rural areas, FTTC currently provides average speeds of 40.8 Mbps,[9] and urban consumers average 49.8 Mbps. Virgin Media has continued to invest in its own HFC network, and now offers speeds of 150 Mbps to consumers within the 50 per cent of the country it covers. Overall (in part thanks to existing government interventions), superfast broadband coverage of 30 Mbps or better is expected to reach 95 per cent of households by 2017.[10] Much higher speeds will be available to most households. By 2020, Virgin will increase its coverage to 17 million premises, or approximately two-thirds of the country.[11] BT says that it *"expects to offer initial speeds of a few hundred megabits per second to millions of homes and businesses by 2020"* using G.fast.[12]

However, some countries – notably Japan, Korea, China, Hong Kong, Singapore, Qatar and New Zealand – have invested substantially in FTTH, which entirely replaces legacy copper. This can enable very high speeds (typically up to 1 Gbps, and potentially even more), provide low latency and reduce operating costs, albeit at a substantial upfront cost.

These international investments are not necessarily a model for the UK however – the social and economic benefits they have delivered are not yet clear. Moreover, they were in part driven by circumstances of time and place. Singapore and Hong Kong have very high population density, which greatly reduces the costs of FTTH. Japan and Korea made their FTTH investment decisions long before cheaper, copper–based superfast broadband technologies were available. China is rolling out FTTH primarily in 'green field' sites where it is a natural choice.

That said, some argue that the UK should be making similar investments in FTTH. For instance, Labour Digital has recently proposed that *"The UK should target nationwide access to 1 Gbps broadband in homes, businesses and public buildings, with 10 Gbps services for tech–clusters, as early as possible in the next parliament."*[13]

This paper:

- Reviews evidence[14] on the benefits and costs of such an investment.
- Discusses the dynamic nature of the investment decision, and highlights issues which could change the optimal approach over time.
- Considers the implications for policy.

3. BENEFITS OF FASTER BROADBAND

While there is copious analysis on the economic and social benefits of broadband, there is far less that looks specifically at the benefits of greater speed. Analysys Mason, in a 2013 report on the benefits of broadband for the European Commission, commented:

> *"Over 200 previous studies and reports were examined for the literature review ... Most of the literature that exists does not consider high-speed broadband explicitly (only 11 per cent mentioned high-speed broadband) and very little has been written about the incremental benefits that result from having high-speed broadband as opposed to lower speeds.*[15]

While there is little analysis of the benefits of higher speed broadband, there is even less on the merits of different varieties of higher speed – for instance, the benefits of 1 Gbps FTTH broadband over those from 80 Mbps FTTC broadband.

In this section we present the results of a number of studies that do look at the economic and social benefits of speed, starting with those looking specifically at FTTH, before moving to more general discussions of speed.[16]

A fundamental challenge faced by empirical work in this area is that the benefits of increasing available speed very much depend on current capacity: doubling speed from, say, 1 Mbps to 2 Mbps might bring substantial benefits, but this may be a poor indicator of the benefits from doubling from 100 Mbps to 200 Mbps. For instance, an Ofcom analysis of the relationship between ADSL line speed and consumer traffic found that while traffic grew steeply as line speed increased from 0 to 6 Mbps, at 8–10 Mbps consumption plateaued – additional speed beyond this brought very little additional usage.[17] (Note that this analysis primarily addressed consumers – results for business customers could well be different).

To take a parallel from electricity, a country suffering regular black-outs and brown-outs would clearly benefit from increased generation capacity, but for a country without such problems investment in capacity may be money wasted.

A critical consideration therefore is whether demand outstrips supply. We therefore conclude this section with a summary of the small number of reports which have considered future demand for bandwidth, though we note that these generally do not attempt to address currently unknown services which may require even higher speeds.

Economic Impact of FTTH broadband

Report	Authors	Date	Methodology	Key finding/claim	Comment
Early Evidence Suggests Gigabit Broadband Drives GDP	**Analysis Group for FTTH Council**	2014	Fixed effects panel data regression model of selected US regions with and without 1 Gbps broadband	1.1 per cent uplift to GDP in US regions from 50 per cent availability of 1 Gbps broadband	Unclear how reverse causation has been corrected for (ie gigabit investment focused on high growth markets). Availability rather than adoption used Result not significant at 5 per cent level
Independent cost-benefit analysis of broadband and review of regulation	**Vertigan Panel for Australian Government**	2014	Cost-benefit analysis Review of applications	FTTH-heavy national broadband network (NBN) would destroy A$1,600 of value per Australian household compared to a plan with more FTTC Vast majority of applications with externalities are possible with 24 Mbps or less. Only exception is potential educational virtual reality	Commissioned by new government with stated policy to shift NBN from an FTTH heavy approach
Optimal Investment in Broadband: The Trade-Off Between Coverage and Network Capability	**Robert Kenny (present author) for Vodafone**	2010	Modelling of consumer willingness-to-pay and costs by geotype for different BB techs to derive required externalities to justify public intervention	A belief in extremely high incremental externalities for FTTH over FTTC is required to justify policy support for FTTH	Analysis based on initial availability of basic BB only – even higher incremental externalities for FTTH required if FTTC already rolled out

Economic impact of faster broadband

Report	Authors	Date	Methodology	Key finding/claim	Comment
Socioeconomic effects of broadband speed	**Ericsson, Arthur D. Little and Chalmers University of Technology**	2013	Propensity Score Matching analysis of international consumer research data	Increased broadband speed benefits household income, but no significant benefits beyond 8 Mbps (in OECD countries)	Methodology cannot rule out reverse causality.
Does broadband speed really matter for driving economic growth?	**Rohman & Bohlin, Chalmers University**	2012	Cross country analysis of OECD countries, 2008–10	Doubling speed adds 0.3 per cent to economic growth	Sample mean bandwidth was 8 Mbps – unclear if relationship holds for increases from higher speeds
UK Broadband Impact Study	**SQW for DCMS**	2013	Modelling based on assumed delta in broadband speed take-up and the Rohman & Bohlin analysis of benefits of speed	Current UK government interventions for faster broadband will add £6.3 billion p.a. of GVA, and return £20 per £1 invested	Critically dependent on applying Rohman and Bohlin's estimates of marginal benefits of faster broad-band speed at 8 Mbps to much higher speed ranges
Myths and realities about the UK's broadband future	**EIU for Huawei**	2012	Qualitative discussion based on interviews and literature review	Construction of superfast will bring economic benefits, but longer term benefits contingent on institutional change, skills and so on	Focused on FTTC – no discussion of incremental benefits of FTTH
Impact of Broadband on the Economy	**ITU**	2012	Survey of econometric studies	Numerous studies point to economic benefits of broadband, but little evidence to date re benefits of faster speeds	
Superfast Cornwall Update Report	**SERIO**	2014	Survey of businesses using superfast in Cornwall	£99 million GVA expected to be created by superfast programme	Superfast Cornwall includes both FTTC and FTTP. Survey did not distinguish between the two
Superfast – Is it worth a subsidy?	**Kenny & Kenny**	2011	Literature review and analysis	Wide range of externality-generating applications (e-health, e-government, smart grids and so on) do not require superfast speeds	
Early effects of FTTH/FTTx on employment and population evolution	**Forzati & Mattsson**	2012	Multivariate regression of Swedish municipalities	Finds weak correlations suggesting 10 per cent increase in FTTH/B coverage in a municipality increases population by 0.25 per cent and employment between 0 and 0.2 per cent	Limited overlap of FTTH with FTTC or HFC, so study is effectively of superfast vs basic broadband
Public Private Interplay for Next Generation Access Networks: Lessons and Warnings from Japan's Broadband Success	**Kenji Kushida (Stanford University)**	2013	Review of Japan FTTH deployment	*"taking advantage of the broadband environment to produce innovation, productivity growth, and economic dynamism, was far more difficult than facilitating its creation"*	

Bandwidth demand forecasts

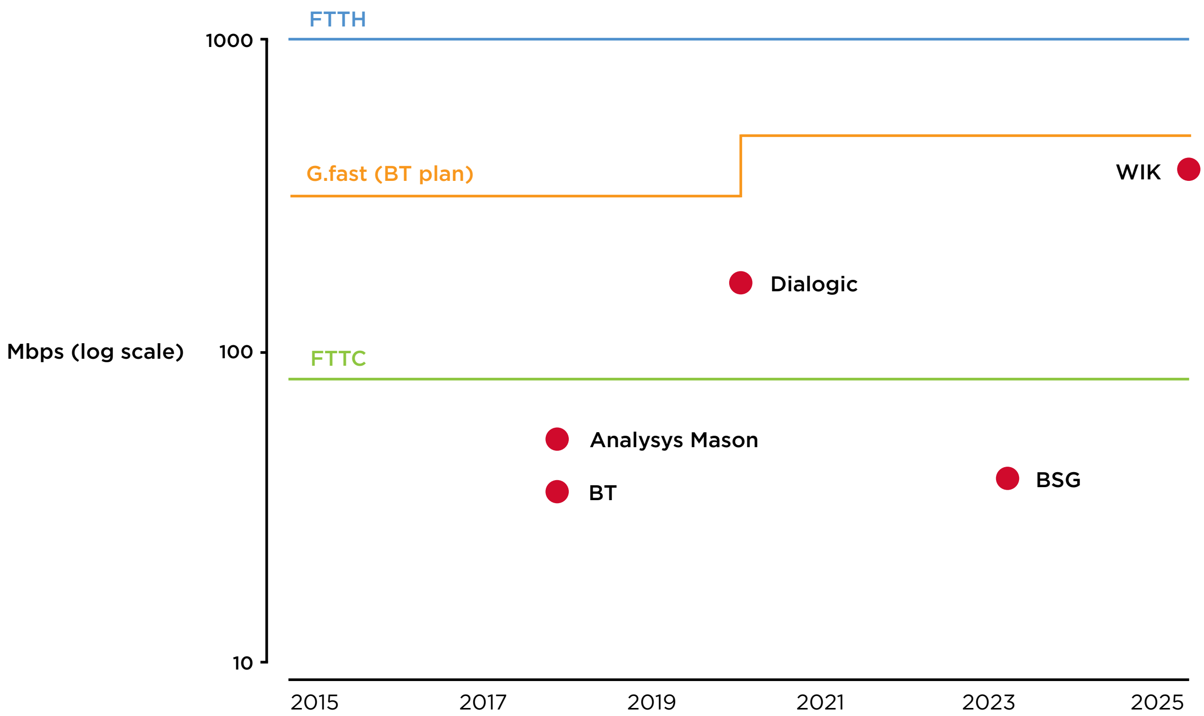
Report	Authors	Date	Methodology	Key finding/claim	Comment
Domestic demand for bandwidth[18]	Communications Chambers for BSG	2013	Bottom-up analysis based on application bandwidth requirements, usage trends household size and probabilistic analysis of simultaneous use	In 2023 the median household will have a requirement for 19 Mbps, top 1 per cent will need 35–39 Mbps	Based in part on proprietary data from UK ISPs. Currently unknown types of application not included
Market potential for high-speed broadband connections in Germany in the year 2025	WIK for FTTH Council	2013	Bottom-up analysis based on application bandwidth requirements and individual and SME usage profiles. Methodology for aggregating HH usage unclear	60–350 Mbps downstream required in 2025, with near symmetric upstream requirements	Some assumed application requirements seem very high (e.g. 25 Mbps for HD communications vs <2 Mbps per Skype, Apple) 100 Mbps for each of cloud services and home working a critical assumption – note that home working and cloud services are both widespread today at far lower speeds
How the speed of the internet will develop between now and 2020	Dialogic and TUE for NLkabel & Cable Europe	2014	Application-based traffic forecast with assumption that bandwidth requirement grows pro-rata to traffic	Average user needs 165 Mbps down and 20 Mbps up in 2020	No evidence offered for critical 'pro rata' assumption[19]
Can you ever have enough bandwidth?	BT	2014	Bottom-up based on applications and exemplar household and usage patterns	95 per cent of households will need less than 35 Mbps in 2018	Limited information on details of methodology
International benchmark of superfast broadband	Analysys Mason for BT	2013	Bottom-up analysis based on representative sample of household types	Top 1 per cent of UK households will need 52 Mbps in 2018	

Bandwidth demand compared to access network capabilities

As we have seen, forecasts for bandwidth demand have a wide range. However, they are all consistent in suggesting that needs for some years ahead at least will be well within the range of copper technologies.

For example, the WIK forecasts (on behalf of the FTTH Council) are the most aggressive, but even these suggest that needs in 2025 will be well within the capabilities of G.fast which has significantly lower cost than FTTH. See page 23 below for a more detailed discussion of G.fast.

FIGURE 2 **BANDWIDTH DEMAND FORECASTS AND NETWORK CAPABILITIES**[20]



4. THE COSTS OF FTTH DEPLOYMENT

Variation in FTTH deployment cost

The cost of FTTH deployment depends on a wide range of factors. These include:

- **National labour costs.** The biggest cost component of FTTH is 'civils' (installing fibre in the ground and into the home) which can represent 80 per cent of the total.[21] This cost sees only moderate benefit from technology development,[22] and is primarily driven by labour costs.
- **Population density.** Areas with denser population are cheaper to serve, since civils costs per household are lower (because fibre lengths are shorter). Population density is a factor both within countries and between countries.
- **Scope.** The importance of population density means that the scope of an FTTH roll-out is an important factor in costs per household. Higher percentage coverage will come at a higher unit cost, since more sparsely populated geographies are included. Analysys Mason estimate that providing FTTH to 'the last 20 per cent' of homes in the UK would cost roughly as much as providing it to all of the other 80 per cent in more densely populated areas.[23]
- **Existing assets.** The availability of capacity in existing ducts can reduce deployment costs. (Note that different countries have very different starting points in this regard.)
- **The party undertaking the deployment.** Generally the incumbent has advantages both in access to existing assets such as ducts and in a large and experienced workforce, reducing costs.
- **The nature of building stock.** Multiple dwelling units (apartments) can be cheaper to serve, though vertical risers (ducts) and building owner permissions can be challenging. Older or historic buildings can be problematic, because new in-home wiring may be required. Set-backs from the curb also increase costs.
- **Greenfield vs brownfield.** For new developments, the cost of FTTH is generally similar to copper, since new ducts and cables must be deployed in either case. However, it is generally much more expensive for existing properties (where the copper is already in place, but fibre must be newly laid).

Thus any estimate of FTTH deployment costs needs to be seen with these variations in mind – in particular, deployment costs in developing markets may not carry over to developed markets; the level of coverage is a key variable, and so on. With these caveats in mind, we provide a range of FTTH deployment cost estimates. Estimates for other countries we have scaled for UK population to provide a crude proxy for equivalent UK costs. A number of estimates are for cost per household, often for particular geotypes. Given the wide variation in costs for different geotypes, we have not scaled these to a UK national figure.

FTTH Cost estimates

Report	Authors	Date	Scope and Coverage	Estimated cost (and £ equivalent)[20]
The costs of deploying fibre-based next-generation broadband infrastructure	Analysys Mason (for BSG)[21]	2008	UK (split by geotype)	£25 billion for national coverage, £13 billion for 80 per cent coverage
Business Plan V5.2	B4RN	2013	UK rural roll-out	£1,116 per home (assuming 100 per cent take-up)
Innovative FTTH Deployment Technologies	FTTH Council	2014	Parham village, UK. ('Tractor broadband' using local agricultural contractors)	£2,000 per home
Szenarien und Kosten für eine kosteneffiziente flächendeckende Versorgung der bislang noch nicht mit mind. 50 MBit/s versorgten Regionen	TÜV Rheinland (for German government)	2013	Germany, nationwide	€85.5 – €93.8 billion [£53-58 billion for UK]
The Cost of Nationwide Fibre Access in Germany	WIK	2012	Germany, nationwide	€70 – €80 billion [£43-50 bilion for UK]
A cost effective topology migration path towards fibre	Frank Phillipson, TNO [Netherlands Organisation for Applied Scientific Research]	2013	Urban Netherlands	€968 [£545] per connection
Modification and development of the LRAIC model for fixed networks 2012-2014 in Denmark	Tera Consultants (for Danish Business Authority)	2013	Denmark national coverage	DKK32.7 billion [£39 billion for UK]
The Italy and Spain NGA cases from a commercial and regulatory point of view	Analysys Mason	2013	'Western European Country' (with 20-25 per cent of premises in MDUs, 33 per cent uptake)	$2,300 [£1,400] per connection
Costs of deploying FTTdp with G.fast	Huawei	2014	Generic model for 'European country'	Per home connected (with 60 per cent market share): Urban $2,100 [£1,300], Suburban $3,300 [£2,100], Rural $5,000 [£3,100]
NBN Co Strategic Review	NBN Co	2013	93 per cent coverage for Australia	A$38.2 billion [£57 billion for UK]
Connect America Cost Model Overview	FCC	2013	Cost model for US carriers	Approx $1,300 [£800] per premise passed investment cost for major carriers (higher for those in more rural areas)
Why Are You Not Getting Fiber?	Calix	2010	Cost for Verizon (in their selected roll-out areas)	$700 per home passed plus $650 per home connected [£440+£410]

Summary

Total costs

The Analysys Mason estimates are the only ones we have been able to identify that quantify costs for a national or near-national UK roll-out of FTTH. Their 2008 estimate of £25 billion is still widely cited.

In general, scaling other European estimates (such as those for Germany and Denmark) for UK population arrives at appreciably higher figures that those from Analysys Mason.

For the 26 million UK households, Analysys Mason's £25 billion estimate implies a per-household cost of £962. This is in the range of the £545 to £2,000 per-household costs set out above for a variety of different geotypes.

Gap finance

The figures above are for the total cost of FTTH deployment. It is at least feasible that the subsidy required to enable FTTH roll-out could be considerably lower. Countries such as Malaysia, New Zealand and France have taken this approach, providing funds to operators (primarily incumbents) to support but not fully fund FTTH. One guesstimate for the UK (the basis for which is not provided) suggests that £3 billion of public funds could trigger a nationwide roll-out.[26]

However, this figure seems optimistic. Gap finance at any moment in time is only viable if the incremental investment solely funded by the commercial sector is anticipated to generate commensurate incremental revenue or cost savings. However the evidence suggests that consumers currently have a low willingness-to-pay for the additional speed and lower latency offered by FTTH[27] and thus the market case is doubtful. FTTH does bring some operational cost savings over FTTC, but given the small portion of total costs represented by opex (typically 5 per cent or less of the capital cost),[28] this isn't generally significant.

Thus in the UK context, it is unclear that the private sector would be able to capture material extra revenues from the at least £22 billion they would be required to fund, even after £3 billion of gap funding. Just the £22 billion would be nine times the £2.5 billion BT is investing in FTTC. Consequently, necessary gap funding for FTTH is likely to be substantially greater than £3 billion.

5. THE DYNAMIC INVESTMENT DECISION

To date the UK has focused primarily on FTTC, both commercially and as a matter of government policy. (Though as we have noted, Virgin offers cable broadband to approximately half the country and expects to increase this to two-thirds, and BT expects to deploy G.fast. There are also some local investments in FTTH –see Figure 3).

Today's available evidence (as set out in the preceding sections) certainly suggests that a traditional cost-benefit analysis would not support intervention for an alternative, FTTH-focused approach.

FIGURE 3 SAMPLE UK FTTH DEPLOYMENTS[29]

Hyperoptic	Sky / Talk Talk / City Fibre	Gigaclear
Offers FTTH to select residential developments, targeting those where it will have low unit costs and good prospects for demand (in part because they are in locations with poor BT connectivity). Plans to pass 0.5m homes by 2018.	The three companies are planning a joint roll-out of FTTH to 'tens of thousands' of homes in York, to launch in 2015.	Operates nine local networks in rural areas, with plans to reach 200,000 homes. Secures minimum volume commitments from communities before deploying.

However, given the fast-changing nature of the market, the evidence base will develop and it is appropriate to keep under review the potential returns from an FTTH investment.

This section explores some of the market developments that have and will in the future influence the merits of intervention in support of FTTH. We consider:

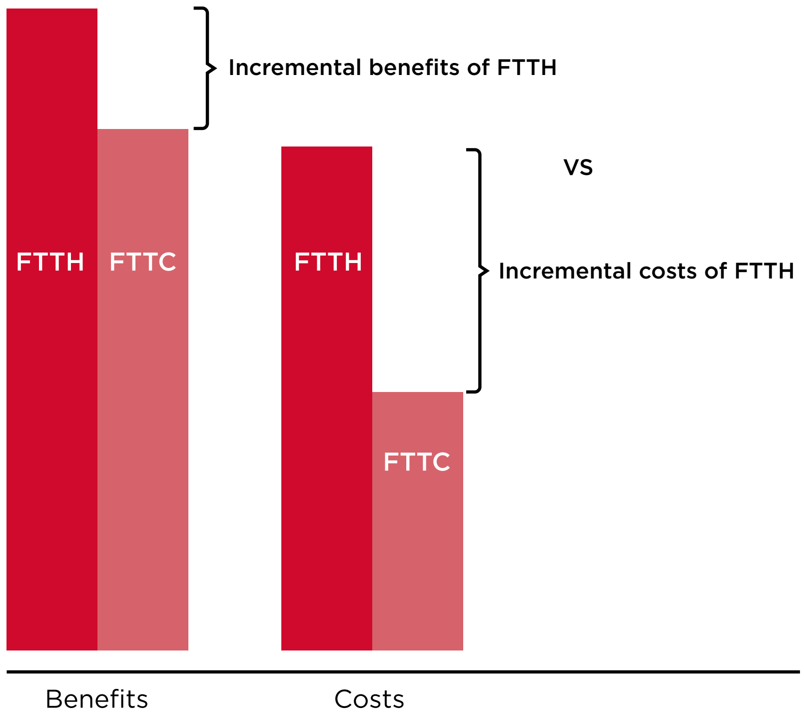
- The impact of the recent roll-out of FTTC.
- Application development.
- Access technology development
- The 'promotional' value of gigabit speeds.
- FTTH's case to be 'future proof'.
- Lead times.
- Regulatory issues.

The recent roll-out of FTTC

The trade-offs of an FTTH investment for the UK are now very different from the way they were at the time of Stephen Carter's Digital Britain Review five years ago. At that time, the UK had solid basic broadband, but limited faster broadband. Virgin was the only network offering greater than DSL speeds, but this offer was not at today's speeds of up to 152 Mbps, and was limited to half the country.

Thus in 2009 FTTH (and indeed FTTC) would have brought a substantial uplift in available capacity. In choosing whether to invest in the cheaper option of FTTC or instead to prefer FTTH, the critical question was whether the incremental benefits for FTTH was more or less than the incremental cost (Figure 4). At the time the general (though certainly not universal) consensus was that the incremental benefits of FTTH were less than the incremental costs, primarily because of the much higher costs of an FTTH solution.

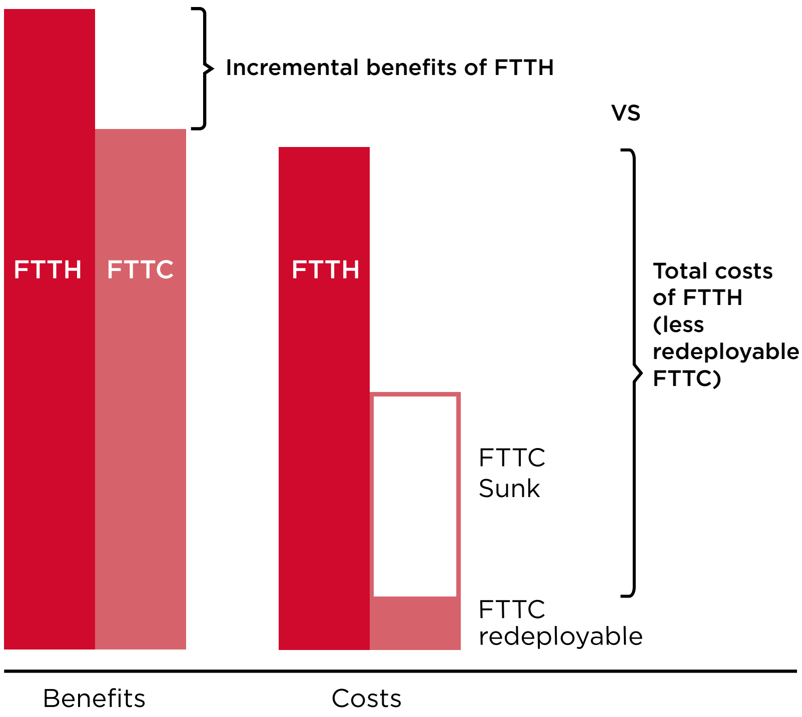
FIGURE 4 **ILLUSTRATIVE '2009' INVESTMENT CHOICE**



The question remains today whether a widespread FTTH roll is justified. However, the investment challenge for FTTH is now significantly harder, because since 2009 the UK has seen the upgrades to BT and Virgin's networks. The cost of these upgrades are sunk, and thus are mostly irrelevant to current decision making. (A portion of the FTTC network will be redeployable for FTTH, however, reducing its net cost).

Consequently, whatever incremental benefits FTTH brings must be compared to the total cost of FTTH roll-out (net of redeployed FTTC), not just the incremental cost over FTTC. (We use FTTC as an illustration – similar logic applies to HFC).

FIGURE 5 **ILLUSTRATIVE '2014' INVESTMENT CHOICE**



To take a parallel, it is currently being debated whether London's next runway should be at Gatwick or Heathrow. Whatever decision is made, clearly once one such runway has been built, it would be hard to immediately justify also building another runway at the other airport.

If we take into account the announced plans of BT and Virgin, then the case for government intervention for FTTH becomes harder to make. Since both companies are deploying technologies with far greater capabilities than FTTC, the incremental benefit of FTTH becomes even smaller.

Application development

Absence of a 'killer app' for FTTH

With the passage of time we have increasing information on both new applications and usage of new and old applications. A 'killer app' for FTTH has not yet appeared. (This is not for lack of an addressable market – as noted earlier, there are already approximately 130 million FTTH connections worldwide).[30]

Ovum has spoken of an 'application vacuum', which *"provides a reason as to why the uptake of fiber services has been muted and telcos are reluctant to move aggressively to FTTH"*.[31] According to Heavy Reading in a recent presentation for the FTTH Council, *"No single application requires FTTH – and there's little sign of such an application is emerging"*.[32] (While presentations for the Council in prior years had acknowledged the absence of a single killer app, the statement that there was no sign of one emerging was new in 2014.)

The respected Pew Research Centre recently published a report *Killer Apps in the Gigabit Age*, based on consultation with numerous internet experts.[33] Strikingly, the applications identified do not (in almost all cases[34]) require substantial bandwidth. For instance, a recurring theme in the report is telepresence. But even high–end, professional telepresence systems (unlikely to be seen in a residential setting for many years) require 18 Mbps or less.[35]

Thus absent a single killer app forcing a requirement for faster broadband, consensus is building that the key driver of bandwidth requirements will be simultaneous usage of multiple applications.[36]

Declining bandwidth requirements for some apps

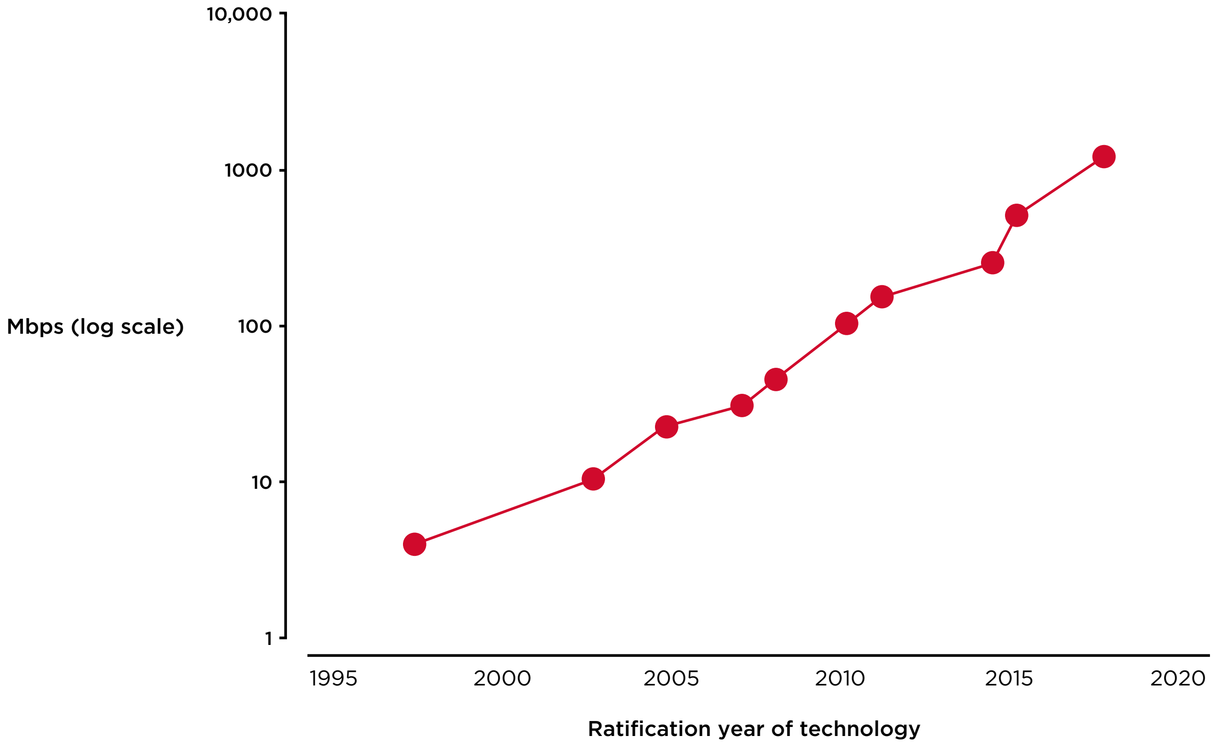
However, while new applications are being developed, and usage increasing, technological improvements mean that existing applications often need less bandwidth over time. Video is a key driver of traffic and bandwidth requirements, for example, but for a given picture quality, it is estimated that the bandwidth needed falls 9 per cent per year or more.[37] Improvements both in picture encoding software and the processing power available to codecs (which compress images for transmission or render them on the consumer device) support this performance improvement.

An additional factor driving reduced bandwidth needs for some apps is the rise of the mobile internet. Application developers are increasingly focused on making their applications usable even on mobile networks. This is driving considerable investment in reducing bandwidth and traffic requirements.[38] While this investment is aimed at use on mobile networks, it also has benefits for users on fixed networks, since the same techniques can be applied there.

Access technology development

In one sense FTTH is already at maturity in that its gigabit capacity is unlikely to be exceeded by demand for the foreseeable future. As we have seen, even the FTTH Council's own forecasts suggest a requirement of just 350 Mbps in 2025.

FIGURE 6 **COPPER (DSL) DATA RATES**[39]



However, copper technologies[40] are developing rapidly (Figure 6). More bandwidth is being squeezed out of the existing copper infrastructure, in part through ever more sophisticated transmission equipment (benefitting from Moore's law), and partially by moving fibre closer to the home, reducing the length of copper over which signals must travel.

The latest generation of copper technology is G.fast. This uses existing copper for the last few tens of meters to the house, and delivers speeds approaching a Gigabit per second. In a recent technical trial, BT achieved 696 Mbps down and 200 Mbps up over 66 meters, and 786 down and 231 Mbps up over 19 meters.[41] Other operators who have been trialling G.fast include Swisscom, Eircom, Telecom Italia, Telekom Austria and TeliaSonera (the incumbent in Sweden and Finland).[42]

Equipment vendors anticipate commercial launch of G.fast equipment in the first half of 2015,[43] with operators (including BT) planning service launches in 2016.[44] BT says it expects speeds for its G.fast service to rise to 500 Mbps over time. This is below the current technical limits, in part because it will be using the technology at its cabinets, rather than extending fibre to distribution points closer to consumers.

Copper technologies like G.fast offer substantial savings over FTTH by avoiding the need to install fibre at each home, a logistically demanding and time consuming task. One typical estimate suggests that G.fast would be 60–70 per cent cheaper than FTTH.[45] (The saving would be even greater if G.fast was deployed at the cabinet, and thus no extension of fibre was required).

Beyond G.fast, even faster copper technologies are in the lab. For instance, Bell Labs has achieved 1 Gbps up, 1 Gbps down on a standard copper pair over 70 meters.[46]

As copper speeds increase, this reduces the probability that there are material numbers of households needing FTTH (or, put another way, pushes out the date when such need will crystalise). This reduces the incremental benefits of FTTH over copper, though of course upgrading to new generations of copper does carry its own cost.

FIGURE 7 **TIME 'BOUGHT' BY G.FAST UPGRADE (ILLUSTRATIVE)**

Assumptions	Result
Cost of G.fast per line: **£350**	The discounted cost of FTTH deployment in **2016** is the same as The discounted cost of deploying G.fast in **2016** and overbuilding with FTTH in **2023** ➡ If FTTH not needed before **2023,** better to deploy G.fast (though deploying neither in **2016** may be preferable)
Cost of FTTH per line: **£1000**	
Portion of G.fast cost reusable in upgrade to FTTH: **50%**	
Discount rate (per Treasury Green Book) **3.5%** [47]	

One way to look at this is to consider the time 'bought' by a G.fast upgrade. Figure 7 shows a simple illustrative calculation. The cost of deploying FTTH in 2016 is (in discounted terms) the same as that of deploying G.fast in 2016 and then upgrading to FTTH in 2023. In other words, if speeds beyond the 700 Mbps G.fast offers are not required until after 2023, then it will be better to first deploy G.fast, even if a later upgrade to FTTH is necessary. As we have seen, even the FTTH Council's forecasts suggest that speed requirements will be within G.fast's capabilities until at least 2025.[48]

Promotional value

Notwithstanding the lack of a technical requirement for extremely fast broadband (in the sense of applications that depend on it), gigabit speeds delivered by FTTH undoubtedly have promotional benefits. This applies both to the companies that offer the speeds, but also to the municipalities that can point to very high-speed broadband. Regardless of the reality, there is a perception that these speeds matter. As one European operator executive has said:

> “*So much of what we are doing on the network side is not being done because people actually need all of this bandwidth, it's being done so that we can put it on an advertising hoarding.*” [49]

A recent survey of broadband providers by Broadbandtrends found that *“being perceived as a Technology Leader was the overwhelming driver for offer(ing) Gigabit Broadband services”*.[50]

The perception of the value of speed may persuade a company to locate in a particular town, or citizens to move to certain neighbourhoods. Of course, if the higher speeds don't actually deliver tangible economic and social advantages, this is essentially a zero-sum game, moving value from one region to another without any national gain. Such national gains can only arise if the perceived benefits result in international relocations of businesses.

‘Future proof’ investments

The ‘future proof’ argument for FTTH acknowledges that immediate benefits may be limited, but makes the point that FTTH will have ample capacity for substantial future requirements, even if today we cannot identify what might drive those requirements. While this argument has merits, it also has limits. In particular:

- The ‘future proof’ argument is less powerful if the alternative is ‘do nothing’. Doing nothing is future proof in that it is a decision which can be easily reversed if a strong case for FTTH becomes apparent. (Or, even if you knew for certain that FTTH was going to have substantial benefits starting ten years from now, the right answer could still be to wait to deploy, if– say – a widespread roll-out only needed five years). However, if money is spent on FTTH, it cannot be recovered if FTTH turns out not to deliver anticipated benefits.
- Even if the alternative is to invest in another technology, because FTTH is so expensive delaying investment in FTTH even by a few years can bring substantial ‘time value of money’ benefits, outweighing the cost of deploying the other technology in the interim, as we have seen.[51]
- As noted above, given developments in copper technology, even if substantially more capacity than FTTC can provide is required, it is not clear that expensive FTTH would be the natural upgrade.

Lead times

As discussed above, it is not clear when or if there will be a technical requirement for FTTH. However FTTH is time consuming to deploy, and would take several years in the UK. Thus it makes sense to start deployment somewhat in advance of the point where it becomes a critical infrastructure. Indeed, if there is ‘clear line of sight’ to the benefits of FTTH, this may be a reason to prefer it to another technology, even if those benefits are not imminent. (If instead FTTH roll-out waited until those benefits came to pass, then much benefit would be forgone during the years it took to roll-out the new network).

Conversely, the later the start of a government-funded FTTH deployment, the greater the coverage of commercially funded FTTH is likely to be, reducing the required gap funding.

Regulatory issues

A further consideration for any direct government investment in FTTH is European state aid regulation. While UK government support for FTTC has been deemed to be legitimate state aid in pursuit of the European Digital Agenda, this is no guarantee that overbuilding FTTC networks with another generation of technology would be compatible with those regulations. Indeed, in its recent update to state aid rules the Commission noted that support for new broadband infrastructure where superfast broadband already exists raises *"potential competition concerns [which] need to be analysed very carefully"*.[52] Thus changes to the rules would likely be necessary.

Any state aid would almost certainly require that the supported network be available to third parties on a wholesale basis. While this is important in sustaining retail competition, it does reduce the margin available to the network builder, making the investment decision more challenging. Moreover, the technical systems to enable wholesaling (including order receipt and tracking, billing, fault management and so on) are not cheap. Any carrier other than BT – which has them already – would need to develop these in addition to making the network investment. (While BT would not need new wholesale systems, the FTTH investment would be particularly unattractive to it, since it would require it to write off the substantial value in its existing copper network).

Conclusion

Thus the decision about fixed broadband infrastructures is a dynamic one, where choices are likely to be 'right for now' but not necessarily in perpetuity. There is also considerable risk, particularly in FTTH investments which (at least for now) fundamentally depend on judgements about currently unknown future benefits. In the next section we turn to the policy implications of this.

6. POLICY RECOMMENDATIONS

Not rolling out FTTH avoids substantial cost, and leaves open the option to deliver the same benefits through much cheaper developing technologies. However, it carries a risk that in time the UK's digital infrastructure becomes sub-optimal in terms of its capabilities.

Thus to ensure that infrastructure remains future-proof, policy makers will need to maintain a strong 'watching brief' and be flexible (albeit this carries a potential cost in policy uncertainty). It also highlights the importance of experimentation[53] and information gathering. These will narrow the range of uncertainty and provide early warning of any need for further investment.

Experimentation

There may therefore be merit in two forms of investigation – local demonstrators and national laboratories.

Local demonstrators

A number of cities worldwide have run experiments and trials of broadband infrastructure and its uses (see the Appendix for a range of examples). Instances in the UK include Future City Glasgow[54] and the BT/Nuel internet-of-things pilot in Milton Keynes.[55] However, neither of these is particularly focused on higher bandwidth applications. It may be that there is value in a trial based in an area with FTTH (such as Hull or – in time – York) to see whether there are socially-valuable applications enabled by very high-speed infrastructure in combination with other forms of broadband.

The potential for FTTH (or more strictly fibre-to-the-premise) to make a difference to creative and tech clusters is also worth exploring. The SuperConnected Cities programme has made vouchers for faster broadband available in areas such as Silicon Roundabout,[56] but thus far has had little take-up. A more concerted and targeted programme to build FTTP adoption in such a neighbourhood may be worthwhile.

Such clusters are perhaps likely to be the first regions and companies to be able to capitalise on any unique benefits of FTTP or other ultrafast broadband (should they come to pass). As such, they can act as a leading indicator, or a 'whistle on the kettle' for those benefits. If they are starting to demonstrate real returns from gigabit speeds, then it may be time to consider beginning a wider rollout of FTTP.

The location of such a demonstrator will involve trade-offs, balancing the existing availability of cheap FTTP, the likelihood that the local companies will be of a type to be substantial users of bandwidth, and the scale of local companies. This last is important because in most parts of the UK very high bandwidths are available to companies, albeit at a cost which is more justifiable to corporate customers.

FIGURE 8 **THE FTTP 'WHISTLE ON THE KETTLE'**

A targeted programme to support FTTP adoption in one or more creative and tech clusters, on the basis that these neighbourhoods are likely to be the earliest to crystalise any benefits uniquely attributable to FTTP.	Adopting firms to be tracked, with the advent of such benefits (if any) acting as a trigger for consideration of wider spread FTTP.

Note that such experiments can have benefits quite aside from any consequent government action. If (for example) FTTP is demonstrated to have value to tech hubs, then this might prompt greater take-up by companies and greater deployment by telcos in such areas, without any further intervention.

National laboratories

Some countries have invested in national institutes to identify uses of widespread faster broadband, such as Australia's Institute for a Broadband Enabled Society.[57] The IBES was created as a companion to that country's FTTH 'National Broadband Network'. While to date it does not appear to have identified applications which uniquely depend on FTTH, the applications it has investigated are no less valuable for that. (Indeed, a worthwhile application that can work on a wider range of speeds is more valuable, since it will be viable for consumers who choose – or only have access to – slower speeds, increasing its user base.)

The UK may benefit from a similar body investigating how to capitalise on the country's existing broadband infrastructure, and (potentially) a future, faster network.

Information gathering

The increasing installed base of FTTH lines globally and the local roll-outs in the UK can provide empirical data on its benefits.

UK evidence

There has been some investigation of the different behaviour of those with higher speed lines compared to those with basic broadband.

Ofcom has reviewed the different data consumption of customers using different technologies.[58] Those using FTTC or FTTH had 78 per cent more traffic than those on ADSL, though there was no difference between those on FTTC and FTTH. However, such comparisons are complicated by selection effects – does fibre increase usage, or do those who have heavier usage switch to fibre?

As UK consumers switch to FTTC, faster HFC and (in areas where it is available) to FTTH, there will be the opportunity to build understanding of the impact of this transition, ideally tracking the impact on individual users to avoid selection effects. Such studies could look both at total traffic, but also at types of usage (as did an Ofcom study of KCOM).[59] For instance, if increased usage is driven by file sharing, this is less likely to justify government support.

International evidence

A potential weakness of empirical analysis of UK FTTH consumers is that those consumers are in a small minority – there is not yet an application ecosystem in the UK that can depend on a sizeable FTTH installed base. This 'chicken and egg' problem may be constraining the potential of FTTH.

However, there are several other markets where there is widespread FTTH, most notably South Korea, Japan, Hong Kong and China. While there is much discussion of these countries' networks, there is relatively little discussion (in English language literature at least) of the applications it has enabled. Has it actually delivered social and economic benefits that would have been impossible without FTTH? (It is notable that despite widespread FTTH, Japan's traffic per line is actually lower than the UK's).[60]

Thus an investigation of how application usage in these markets differs from markets with lesser bandwidth would be valuable. Has the infrastructure investment delivered tangible returns?

7. APPENDIX : BROADBAND INFRASTRUCTURE EXPERIMENTS

In this section we set out a sample of experiments, current and historic, related to broadband infrastructure and its uses. These cover both the deployment of new infrastructure and ways in which to maximise the value of current infrastructure (both FTTH and otherwise). Some are purely commercial, others are research-led or state funded.

We have focused on those deployed in real-world (non-laboratory) environments.

Location	Name	Year	Description	Cost/funds available	Type of network
Australia (Melbourne)	**Institute for a Broadband-Enabled Society**[61]	2009	The IBES initiative conducts a range of research projects across four themes: business and government, culture and community, education and learning, and health and ageing. Their stated aim is *"to become a leader in the development of broadband services and innovation for the benefit of Australian society".*		
UK (Surrey)	**5G Innovation Centre (5GIC)**[62]	2013	Testbed at the University of Surrey which will be used to develop the next (5th) generation of ultrafast Mobile Broadband technology. Funded by HEFCE, Ofcom, and a wide range of commercial players	£41.6 million+	5G
US	**US Ignite**[63]	2012	A public-private partnership between government organisations and a range of municipalities which aims to *"foster the creation of next-generation Internet applications that provide transformative public benefit".* Aims to deliver 60 next generation applications and 200 community test beds over the next five years, with a focus on six main areas: education and workforce, energy, health, public safety, transportation and advanced manufacturing.[64]	Leveraging $40 million investment in GENI	Various
UK (Glasgow)	**Future Cities Glasgow**[65]	2012	A collaboration between public and private sector agencies, and funded by the Technology Strategy Board (TSB), the initiative is a widespread testbed of the use of technology. Demonstrator projects will address issues such as health, safety and sustainability through the use of open data, apps, portals and citizen science mapping. Analysis of data collected during the demonstrator will assist policymakers and inform future investment.	£24 milion	
Spain (Barcelona), Italy (Trento), Belgium (Kortrijk)	**Smart City initiatives/ SPECIFI**[66]	2012	Barcelona initiative aims to test a *"Creative Ring of ultrafast Internet"* including real time culture co-creation, share and distribution. The Trento initiative provides an ICT platform capable to offer services to promote the local territory, attract tourists and support them during their visits. The Kortrijk initiative focuses on providing open APIs from Internet of Things and Next-Generation Media platforms to application creators.	€5.7 million (all three Smart Cities)	FTTH, wireless
US	**Google Fiber**	2011	Google began rollout of Google Fiber on March 30, 2011 by announcing that Kansas City, Kansas would be a first testbed for its 1 Gbps service. Google Fiber has since rolled out to Provo and Austin		FTTH
UK (Cornwall)	**Superfast Cornwall Labs**	2013	Part of the £132 million[67] Superfast Cornwall FTTH rollout, the Superfast Cornwall Labs initiative includes research products covering improving social interaction between deprived neighbourhoods, eHealth, eServices and broadband innovation feasibility studies.[68]		FTTH & FTTC
UK	**Scottish Borders Rural Broadband**[69]	2013	Wireless broadband infrastructure platform offered by local community, part of the £410 million Digital Scotland project	£7.5 million	
UK (Various)	**Super Connected Cities connection vouchers**[70]	2011	Government funded initiative to provide Broadband Connection Vouchers to 22 SuperConnected Cities	£150 million	FTTH

Location	Name	Year	Description	Cost/funds available	Type of network
UK (York)	**York FTTH**[71]	2014	Four telecoms groups, led by Sky and TalkTalk, are building a FTTH network capable of delivering speeds of up to 1Gbps to 200,000 users. The network will be built by Fujitsu and CityFibre, a British firm which already owns 29,000km of fibre and sells high speeds to public sector, mobile network and business clients.	£10 million	FTTH
UK (Milton Keynes)	**Public internet of things network**[72]	2014	Initiative led by BT and Neul to establish Internet of Things (IoT) pilot and build a M2M white space network with static and mobile sensors. The firms will install base stations across Milton Keynes to create a testbed for the council and other public- and private-sector organisations to try out IoT applications such as digital parking spaces, smart rubbish bins, rodent traps, soap dispensers, water meters and central heating systems.[73]		Various
UK	**Digital Advanced Rural Testbed (DART)**[74]		The DART project to build a testbed that incorporates advanced infrastructure broadband using satellite to allow open and flexible experimentation by third parties (e.g. content and application providers). Technology enablers were implemented to support creation of new services, applications and business models.	£344,795	Satellite

ENDNOTES

1. Virgin Media (2015) Virgin Media and Liberty Global announce largest investment in UK's internet infrastructure for more than a decade (http://about.virginmedia.com/press-release/9467/virgin-media-and-liberty-global-announce-largest-investment-in-uks-internet-infrastructure-for-more-than-a-decade).
2. Within this, those taking BT's more recent 'upto 76 Mbps' product receive 62 Mbps. Ofcom (2014) ' UK fixed-line broadband performance, May 2014.' London: Ofcom.
3. Subject to successful completion of trails. BT (2015) BT CEO sets out ultrafast broadband vision (http://home.bt.com/news/bt-life/bt-ceo-sets-out-ultrafast-broadband-vision-11363958493131)
4. FTTH Council Europe (2014) Press Conference @FTTH Conference, 19 February 2014.
5. ADSL 2+: Advanced Digital Subscriber Line. FTTC: Fibre to the Cabinet. HFC: Hybrid Fibre Coax. G.Fast: ITU G series recommendations, 'fast access to subscriber terminal'. FTTH: Fibre to the Home.
6. BT (2012) ' Fibre Technology Deployment for Next Generation Broadband: BT Views on the Policy Agenda.' London: BT.
7. DCMS and HM Treasury (2014) ' Digital Communications Infrastructure Strategy - Consultation Document.' London: DCMS and HM Treasury.
8. BT (2014) 'Results for the Second Quarter and Half Year to 30 September 2014.' London: BT.
9. Ofcom (2014) 'UK fixed-line broadband performance, May 2014.' London: Ofcom.
10. DCMS and HM Treasury (2014) 'Digital Communications Infrastructure Strategy -Consultation Document.'London:DCMS and HM Treasury.
11. Virgin Media (2015) Virgin Media and Liberty Global announce largest investment in UK's internet infrastructure for more than a decade (http://about.virginmedia.com/press-release/9467/virgin-media-and-liberty-global-announce-largest-investment-in-uks-internet-infrastructure-for-more-than-a-decade).
12. BT (2015) BT CEO sets out ultrafast broadband vision (http://home.bt.com/news/bt-life/bt-ceo-sets-out-ultrafast-broadband-vision-11363958493131).
13. Note that Labour Digital did not explicitly reference FTTH, but in practice such speeds will (in the short to medium term) only be practical via FTTH. Labour Digital (2014) 'Number One in Digital.' Labour Digital.
14. We make no claim that this paper offers an exhaustive survey of available evidence, but we believe it to be representative.
15. Analysys Mason and Tech4i2 (2013) 'The socio-economic impact of bandwidth.' Study prepared for the European Commission. Luxembourg: European Commission.
16. We have not included studies looking at consumer satisfaction - see for example Felten, B. (for FTTH Council Europe) (2014) 'FTTH/B Makes a Real Difference.' And RVA (for FTTH Council) (2013) 'Communication Technology In Next Generation Developments.' Tulsa OK: RVA. These FTTH Council studies report higher satisfaction on the part of consumers with FTTH, but this is fundamentally a private benefit and therefore less relevant to a discussion of policy interventions.
17. Ofcom (2014) ' Infrastructure Report 2014' London: Ofcom. Note that there is a further step up in usage at approximately 28 Mbps. However, this is likely to be because beyond this speed customers are a self-selected group who have chosen superfast, rather than because of any inherent impact of that higher speed. Evidence for this interpretation comes from the very moderate growth in usage beyond 28 Mbps.
18. See also a report for the Australian government, applying the same methodology to that market: Kenny, R. and Broughton, T. (2014) 'Domestic bandwidth requirements in Australia.' Communication Chambers.
19. Traffic can change dramatically without changing peak bandwidth. For instance, if a household's peak bandwidth is set by (say) HDTV viewing, an increase in hours of viewing could have a material impact on traffic, but no impact at all on peak bandwidth 16.
20. Maes, J. (2014) 'The Future of Copper.' Boulogne-Billancourt: Alcatel-Lucent.
21. FTTH Council Europe (2014) ' White Paper: Innovative FTTH Deployment Technologies.' Brussels: FTTH Council Europe.
22. Though there certainly have been useful developments, such as 'microtrenching'.
23. Analysys Mason (2008) 'The costs of deploying fibre-based next-generation broadband infrastructure.' Cambridge: Analysys Mason.
24. Where appropriate, £ figures have also been scaled for population differences.
25. See also Analysys Mason for the EC (2013) 'The socio-economic impact of bandwidth.' Luxembourg: European Commission. This pan-European study included a generic cost model which provided an estimated cost of national FTTH for the UK of €22.6 billion [£18 billion]. Analysys Mason regard the £25 billion figure resulting from the 2008 UK-specific model as the better figure to use for UK policy purposes.
26. Stanislawski, S. (2014) 'Response to DCMS Consultation.' Ventura Team.
27. See for instance, BSG (2012) 'Demand for Superfast Broadband.'London: Broadband Stakeholder Group; Vertigan Panel for Australian Government (2014) 'Independent cost benefit analysis of broadband and review of regulation.'; Hartley, S. (2013) ' Is FTTH necessary?' London: Ovum.
28. Campbell, L.H., Chow, E. and Ip, K. (2007) 'Comparative Costs for Fibre to the Node and Fibre to the Home Rollouts in Australia.' London: Ovum.
29. Reilly, D. (2014) 'Hyperoptic FTTH broadband rollout reaches 150 properties.'Cable.co.uk; Talk Talk (2014) 'TalkTalk and Sky partner with CityFibre to Launch Ultra-Fast Broadband.'; Financial Times (2014) 'Rural broadband group Gigaclear targets Aim.' See also Prism (2014) 'Report On UK NGA Provision by Non-Major Providers - A Prism Business Consulting Report for Ofcom' Darlington: Prism Business Consulting.
30. FTTH Council Europe, Press Conference @FTTH Conference, 19 February 2014.
31. Ovum, Is FTTH necessary?, 26 February 2013.
32. Heavy Reading, European FTTH Forecast, 2013-2018, 19 February 2014.
33. Pew Research Center, Killer Apps in the Gigabit Age, 9 October 2014.
34. Some cited applications, such as 'immersive 3D experiences' and 'holographic representation' are of unknown bandwidth.
35. Cisco, Cisco TelePresence Application, November 2010; Polycom, Open Telepresence Experience OTX 300, June 2010.
36. Such 'app stacks' were a key part of the methodology for four out of the five bandwidth forecasts discussed at page 12 33. ZetaCast, Technical Evolution of the DTT Platform, 2012.
37. ZetaCast, Technical Evolution of the DTT Platform, 2012.

38. For a detailed discussion, see Facebook, Ericsson and Qualcomm (2013) 'A Focus on Efficiency.'
39. Maes, J. (2014) 'The Future of Copper.' Boulogne Billancourt: Alcatel-Lucent.
40. By copper technologies we mean transmission equipment using copper wires (possibly in addition to fibre) – the wires themselves are simply the existing phone lines and remain unchanged.
41. BT Press Release (2014) 'BT Trials Prove Potential for Ultrafast Broadband Over Copper.' 25 September 2014.
42. Brown, T. (2014) 'Assessing the NBN rollout & the opportunity the NBN presents the telecom industry.' NBN Co.
43. Aittokallio, A. (2014) 'ADTRAN to launch commercial G.fast in Q2 2015.' Telecoms.com.
44. Shankland, S. (2014) 'Lowly DSL poised for gigabit speed boost.' CNET.
45. Van den Brink, R.F.M. (2013) '4GBB, G.fast and beyond.' DSL Seminar.
46. Alcatel-Lucent (2014) 'Alcatel-Lucent sets new world record broadband speed of 10 Gbps for transmission of data over traditional copper telephone lines.' Press Release 9 July 2014.
47. HM Treasury (2011) 'The Green Book - Appraisal and Evaluation in Central Government.' London: HM Treasury.
48. Note that the WIK forecast for the FTTH Council suggested high end users would require 350 Mbps up and down. While the G.fast trials have typically provided higher down speeds and lower up speeds, this balance is configurable within G.fast, so that 350 Mbps up and down could be offered if required.
49. Brown, T. (2014) Broadband race shifts up a gear. 'The Australian Financial Review.' 15 July 2014.
50. Mastrangelo, T. (2014) 'Gigabit Broadband Services Strategies & Vendor Rankings.' Broadbandtrends.
51. For a discussion of this trade-off, see also Bell Labs (2014) 'Broadband Access Modelling.' April 2014 and Vertigan Panel (2014) 'Independent cost–benefit analysis of broadband and review of regulation.'
52. EC (2014) 'State aid: Commission adopts new General Block Exemption Regulation (GBER).' Brussels: European Commission.
53. For the theoretical underpinnings of this, see Bakhshi, H. et al., (2011) 'State of Uncertainty Innovation policy through experimentation.' London: NESTA.
54. Glasgow (2013) 'Glasgow wins £24 million Future Cities competition.'
55. BT (2014) 'BT pioneers 'Internet of Things' open network in Milton Keynes.' Garside, J. (2014) Milton Keynes trials city-wide public 'internet of things' network. 'The Guardian.' 22 May 2014.
56. DCMS (2013) 'Stimulating private sector investment to achieve transformation in broadband in the UK by 2015.' London: DCMS.
57. The Institute for a Broadband-Enabled Society 'About IBES.' Site accessed November 2014.
58. Ofcom (2014) ' Infrastructure Report 2014' London: Ofcom.
59. KCOM is the incumbent telco in Hull. Ofcom (2013) 'Infrastructure Report 2013 Update.' London: Ofcom.
60. Kenny, R. and Broughton, T. (2014) 'Domestic bandwidth requirements in Australia.' Communications Chambers.
61. The Institute for a Broadband-Enabled Society 'About IBES.' Site accessed November 2014.
62. University of Surrey (2013) 'Plans for 5G Innovation Centre in Surrey Move to the Next Level.'
63. CCCBlog 'Administration Announcing US Ignite Broadband Initiative.' 13 June 2012.
64. US Ignite 'What is US Ignite?' Accessed November 2014.
65. Glasgow (2013) 'Glasgow wins £24 million Future Cities competition.' January 2013.
66. European Commission (2012)'SPECIFI: Smart Platforms Enabling the Creative Industries for the Future Internet.' Brussels: European Commission.
67. Curtis, S. (2014) Cornwall claims 'half' of UK's direct fibre broadband links. 'The Telegraph.' 24 July 2014.
68. Superfast Cornwall 'Superfast Cornwall Labs.' Accessed November 2014.
69. BBC (2014) 'Scottish government announces £2.5m for rural broadband.' 14 July 2014.
70. DCMS (2013) 'Stimulating private sector investment to achieve transformation in broadband in the UK by 2015.'London: DCMS.
71. TalkTalk and Sky plan to build own fibre network. 'Financial Times.' 15 April 2014.
72. BT (2014) 'BT pioneers 'Internet of Things' open network in Milton Keynes.'
73. Garside, J. (2014) Milton Keynes trials city-wide public 'internet of things' network. 'The Guardian.' 22 May 2014.
74. UK Government (2014) 'Innovate UK funded projects.' London: UK Government.

Nesta...

1 Plough Place
London EC4A 1DE

research@nesta.org.uk
@nesta_uk
www.facebook.com/nesta.uk

www.nesta.org.uk